SCREEN FLOW - A MEANS OF MEASURING THE FLOCCULATING EFFICIENCY OF A POLYMER SOLUTION

Contract No. OSU81-00264 with the Department of Supply and Services for Ministry of Energy, Mines and Resources

Final Report

by

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SUMMARY

The purpose of this study was to determine how the flocculating effectiveness of a polymer solution is related to its extensional viscosity. This latter property creates remarkably high pressure losses in flow through screens, and consequently the work attempted to relate the screen flow behaviour of a polymer solution to its ability to promote settling of a suspension.

The first part of the work, conducted at the University of Toronto, was an examination of screen flows for three high - molecular - weight polyacrylamides: one each of a nonimic, anionic and cationic sample. The test section comprised four screens made from electric shaver heads (with .50 mm openings) and measurements of pressure loss and flow rate were obtained for solutions of various concentration and solutions degraded by excessive shearing. Data showed that the pressure drop for a solution was many times the value for the solvent alone — at least ten times for a concentration of 200 parts per million — and that this measured effect varied considerably with concentration and the degree of degradation.

A flow instrument was designed from these results and built for use in a laboratory or field setting. The flow section consisted of several screens in series with a venturimeter for flow rate measurement. The dimensions of the venturi were chosen such that the same pressure transducer could measure both venturi pressure drop and head loss across the screens. The test section, electronic instrumentation and associated piping were installed in a suitcase for easy protability.

To determine the correlation between instrument, measured pressure drop and flocculating ability, preliminary tests were conducted at the Western Research Laboratory in February, 1982. The test fluids were the same three polyacrylamide samples of the initial studies, and these were prepared at different concentrations and subjected to various amounts of degradation. The flocculating ability of a solution was assessed by measuring the settling speed of a clay suspension to which the polymer had been added. The results are not conclusive and further systematic tests are required — including corroborative measurements of intrinsic viscosity and molecular weight (by light scattering) — but the data confirm the expectation that degraded solutions produce less effect in the screen flow instrument and are less effective in settling clay suspensions.

INTRODUCTION

This report describes the work carried out to fulfill DSS contract No. OSU81 - 00264 for the Ministry of Energy, Mines and Resources. The work was conducted at the University of Toronto in the Department of Mechanical Engineering and at the EMR Western Research Laboratory in Edmonton. A copy of the original Research Proposal, which became part of the Contract, is included in this Report as Appendix A.

The work was carried out in three phases and consequently the Report is organized in this fashion. Part I describes experiments, at the University of Toronto, on the flow of dilute polyacrylamide solutions through fine screens. The aim was to characterize the non-Newtonian behaviour of this flow such that a flow instrument could be designed from the results. Part II describes the design and fabrication of the instrument. By measuring the pressure drop across a screen, the device provides a measure of the extensional viscosity of a test liquid. It was thought that, because this non-Newtonian property is highly dependent on polymer molecular weight, it should correlate with the flocculating ability of a polymer sample. Tests to ascertain the degree of correlation were carried out at the Western Research Laboratory (WRL) and are reported in Part III.

PART I

FLOW OF DILUTE POLYACRYLAMIDE SOLUTIONS THROUGH FINE SCREENS

I.1 Objectives

These tests were conducted to explore non-Newtonian behaviour of flow of polyacrylamide (PAM) solutions through screens. Prior research (refs. 1,2,3) has shown that pressure drop across a screen is much larger for a polymer solution than for water under certain flow conditions. Moreover, these tests have indicated that the enhanced pressure drop is very much dependent on the concentration of the solution and on the molecular weight of the sample. The objective of the U of T tests was to carry out a full range of tests with PAM samples supplied by WRL, systematically varying the concentration and changing the molecular weight by shear degrading the polymer. It was hoped that these tests would reveal the best conditions for a flow instrument, in particular, the flow rate, screen size and so on such that the enhanced pressure drop would be large and therefore easily measured in the instrument. A preliminary series of tests was carried out first to determine design parameters for the instrument and these were followed by a comprehensive set of experiments.

I.2 Experimental Apparatus and Technique

The equipment for the screen tests is shown schematically in Figure I-1. Test liquids were driven by gravity through a test section comprised of four screens.

The screens were made from the cover heads of electric shavers and were mounted about 1 cm apart in the 2.5 cm diameter test section. Figure I-2 illustrates details of the screen geometry. Upstream of the test section was a finer screen which acted as a filter, preventing large particles and undissolved polymer lumps from disturbing flow through the screens. Four screens in total were installed to provide an easily measurable differential in the range of the transducer. As indicated in Figure I-1, pressure drop across the test section was measured by a calibrated pressure transducer and flow rate was determined by weighing the efflux over a timed interval.

Test liquids were distilled water and dilute solutions of PAM in distilled water. The polymer samples were supplied by WRL - one each of a nonionic, anionic and cationic PAM. Characteristics of the polymers, such as molecular weight distribution or mean molecular weight, were not provided. Solutions of the anionic PAM were buffered by .02 M sodium sulphate, yielding a fluid with a pH close to neutral. This salt did not buffer the cationic PAM, however, and a variety of solutions were made for test purposes: some with no salt, which yielded a pH around 4.8, some with sodium sulphate, which gave pH's around 4.8, and some with sodium sulphite to attain a pH of 7.0.

Tests were carried out with different concentrations of each polymer to understand the characteristics of the supplied

samples and to provide a frame of reference for later degradation studies. To study the influence of molecular weight, 200 ppm solutions of each polymer were subjected to varying degrees of degradation and then screen tested. Preliminary tests showed that the nonionic and cationic PAMs were particularly susceptible to degradation and thus these solutions were degraded by a household mixer (for baking, etc) at low speeds. The anionic PAM, however, was quite resistant and consequently a blender was used to degrade this polymer. The degree of degradation was increased by turning up the rotational speed and/or by lengthening the period.

The procedure for a series of tests, whether of concentration or degradation, was to first run with water to verify that the screens and instruments were functioning properly. Then a solution was tested over the usual range of flow rates, and afterward water was again tested at a few flow rates. This sequence was followed for every solution, to ensure that any enhanced pressure drop was a non-Newtonian effect and not due to partial blocking of the screen openings.

I.3 Preliminary Tests

Preliminary runs were made to establish the general behaviour of the polymers and, more importantly, to provide data for the design of the flow instrument (Part II). Since we were informed that 200 ppm was to be the working concentration for the instrument, each PAM was tested at that concentration; also, a series of concentrations for the nonionic sample were tested.

Data for the nonionic PAM, from 10 to 500 ppm, are presented in Figure I-3 along with results for water (water data at lower flow rates have been omitted). One should first note that the slope of the water data approaches 2.0 at the highest flow rates, which is expected because the Reynolds number there is around 30. Secondly, the data demonstrate that the polymer remarkedly increases the pressure drop across the screens — 20 ppm increases the pressure drop by a factor of two and 500 ppm produces a 30-fold increase. Evidently this particular flow is very dependent on the amount of polymer present.

The non-Newtonian contribution in Figure I-3 is more easily appreciated when the ordinate is the ratio of the head loss for a polymer solution to that for water, at the same flow rate. This is the form chosen in Figure I-4 to illustrate results for the three PAM solutions at 200 ppm. The data show that the relative head loss for all three polymers is about 5 to 10, certainly an easily distinguishable non-Newtonian effect.

These data confirmed our original expectations that screen flow produces a sizeable non-Newtonian effect similar to what has been found previously (1). The large effect meant that the flow instrument could be straightforwardly designed, and also suggested that this flow may be a sensitive test of polymer molecular weight. A complete series of tests were then undertaken for all three polymers, varying concentration and degradation.

I.4 Systematic Tests

Each of the three polymers was tested in a series of concentrations, starting at 10 ppm and progressing geometrically to 320 ppm. Like the last graph, results are given as head loss ration, $\Delta h_{PAM}/\Delta h_{w}$, versus flow rate and are presented in Figures I-5 to 8. The nonionic sample was done twice (Figures I-5 and I-6), and the discrepancy in the results is believed to be due to different methods of solution preparation for this easily degraded polymer. Nevertheless, there is a consistent pattern in the 4 graphs relating head loss to concentration and flow rate.

This consistency is more evident when the data are normalized, which is done by comparing the relative head loss for a particular concentration to that for 320 ppm, the largest concentration. Data normalized in this way are presented in Figures I-9 to 12; for economy of notation, let H be defined as $\Delta h_{PAM}/\Delta h_{H_2O}$, so that the ordinate in these graphs is H(conc)/H(320 ppm). The plots of H versus concentration verify that dependence on concentration is the same for all three polymers, at least in a relative sense.

Test results for degraded polymer solutions are given in Figures I-13 to 16. Like the concentration series, tests were repeated for the nonionic sample and the data are in Figures I-13 and I-14. The data in these two Figures have similar patterns even though the degradation histories were not the same (and couldn't have been). All four graphs

demonstrate that head loss across the screens is very sensitive to the amount of degradation and therefore to the molecular weight.

Following the format for the concentration tests, it is instructive to plot the degradation data in normalized coordinates. Since the concentration is fixed, the ordinate in this case is H(degraded)/H(fresh), and results are presented in this fashion in Figures I-17 to 20. The data for these graphs are from their counterparts, Figures I-13 to 16. The normalized data reveal a trend that is not apparent in the original graphs: namely, that degradation affects the non-Newtonian effect more at high flow rates, for the data all have negative slopes. This pattern suggests that the degradation process affects the high molecular portion of the distribution, a wholly expected effect for molecules broken by excessive shear.

1.5 Corroborative Studies

Samples of the degraded solutions were retained for measurement of their molecular weights by light scattering. Since WRL owns a LALLS (Low Angle Laser Light Scatterer), it was anticipated that samples could be straight forwardly tested there. Unfortunately, the instrument was not functioning properly and consequently the samples were forwarded to Prof. A. Hamielec of McMaster University, who also owns a LALLS. However, results of his tests are not yet known. When they are available, they will be sent to WRL by letter, along with an assessment of the relation between reduced screen head loss and reduction in mean molecular weight.

I.6 Ionic Strength of Solutions

Experience with the two ionic polymers showed that hydrodynamic effects depended considerably on ionic concentrations in the solution. The cationic polymer was found to be quite sensitive, and consequently a series of screen tests were carried with various concentrations of salts. The results are given in Figure I-21, along with the descriptions of the fluids and their pH values. The data confirm the influence of salt concentration and thus the necessity of carefully controlling ionic strength in any tests with these polymers.

I.7 Conclusions of Part I.

The results presented in this section lead to several straightforward conclusions:

1. The head loss across a screen is a sensitive measure of the non-Newtonian character of a polymer solution, i.e. of its extensional viscosity. This agrees with findings by earlier researchers, eg. Batycky and Masata (1).

2. The head loss depends markedly on the concentration of polymer in solution.

3. The head loss drops significantly when a solution is shear degraded; pending Prof. Hamielec's light scattering data, these drops likely correlate with reduced mean molecular weight.

4. The head loss of an ionic polymer solution (anionic or cationic) depends significantly on the ionic strength of the solution.

PART II

DESIGN AND CONSTRUCTION OF FLOW INSTRUMENT

From the tests conducted in Part I of this study a flow instrument was designed and constructed. Since it was to be used in either a field or a laboratory setting, the instrument was packaged into a suitcase for ease of transportation.

This section details the configuration of this apparatus along with design considerations, operating instructions and calibration tests.

II.1 Design Parameters

This section outlines the considerations which dictated the size, configuration, and performance of the equipment.

II.1.1 Screens

The screens used for the studies of Part I were chosen for the flow device. The prior work showed that these screens were easy to clean, produced sufficiently large non-Newtonian effects for the dilute polymer solutions, had pore sizes (0.020") which would not likely be blocked, and were identical in opening sizes from one screen to another. As indicated earlier, the screens were cut from replacement shaving screen heads for Schick flexamatic electric shavers.

Because the pressure drop across a single screen was low, four screens in series were judged necessary to bring

the expected pressure drop within the working range of the most sensitive transducer available. The largest screen opening practical (724 holes) was used to minimize any effects that perimeter holes would have on the overall pressure drop and to provide a more easily measurable flow rate. The geometry of the hole openings is illustrated in Figure II-2.

II.1.2 Choice of flow rate range

Flow rates in the laboratory tests of Part I were judged too small to be readily measured in a field situation where no weighing tanks would be available. Accordingly, the largest practical flow rate, 10 cm^3/sec, was chosen based on screen size limitations. A venturi configuration was chosen to measure flow rate because flow in this type of device is inertial and thus polymer additives would have the least non-Newtonian effect. Also, a venturi provides a differential pressure proportional to the square of the flow rate which means that the same transducer could be used for flow rate and screens. A selector valve was installed on the transducer to switch the pressure measurement to either the venturi or the screens.

Having decided to use a venturi, the most suitable throat size was dictated by two factors:

1) producing a pressure differential measurable for the operating range of the screens, and

2) having a profile design which would produce substantially the same pressure drop for a given flow rate regardless of the polymer type and concentration.

To determine the optimum geometry, six venturis were built with each one having a pressure drop over the desired flow rate range. The six were tested with several polymer solutions to find the geometry which was least affected by the polymer. The geometries and pressure drop versus flow rate behaviour are given in Figure II-3. Since it was clear that venturi No. 3 was the most suitable, it was installed in the flow instrument.

II.1.3 Pressure Differential Measurement

Because the pressure differentials are in a low range, a transducer is the only practical way to measure the differential. The P7D variable-inductance transducer, made by Celesio Products of California, was selected because of our familiarity and satisfaction with this product and because of its high resolution at low pressures. An accompanying Model CD 10 carrier demodulator was also purchased to convert the transducer signal to a linear voltage output proportional to pressure. Figure II-4 shows the calibration curve for the transducer.

II.1.4 Driving Pressure

The liquids which would be tested in the flow equipment could be quite variable. It was originally thought that a self-priming pump in series with the flow section would be ideal, but tests with two such pumps revealed that the impeller noise (pressure fluctuations) and shear degradation of the polymer were too large to be tolerable. Hence no pump was connected in line to the equipment. It was apparent that

the equipment would have to be fed directly from a pressurized source (overhead tank, say) or sucked into the instrument using the low throat pressure of a venturi connected to a recirculating water pump. Accordingly, a pump and a venturi of appropriate sizes were supplied with the equipment.

II.2 Design and Construction

Figure II-5 and the photo of Figure II-I show the overall configuration of the equipment and details are given in the following sections.

II.2.1 Screen and Venturi Flow Section

In order to keep the apparatus as simple as possible, the inlet filtering screen, the monitoring screens and the venturi were built into a single flow housing. This housing was machined from Delrin, an easily-machined plastic inert to polymer solutions. On the inlet side, a screw-on cap locked into place two fine-mesh screens (for filtering out debris and lumps of undissolved polymer), while a downstream cap contained the venturi and locked in the monitoring screens. The screens were mounted on aluminum bushings which were sealed with O-rings. This section, along with its internal components, is shown in Figure II-6. Three pressure taps protuded from the housing for measurement of the monitoring screen pressure differential and the venturi pressure drop.

II.2.2 Transducer and Controls

The transducer and associated piping were constructed separately so that the flow sections could be detached for

disassembly and cleaning. The piping connections for the transducer are shown in Figure II-5. A valve between the high and low pressure side of the transducer was provided to enable a quick and easy check of zero pressure differential. A shut-off valve and a selector valve were located on different sides of the transducer to isolate the transducer from the pressure source as well as to provide for selection between two inputs. Ball valves were used throughout to minimize pressure transients in switching.

II.3 Operation

The following section outlines the procedures involved in operating, calibrating and troubleshooting the equipment. The various controls and components are labelled in Figure II-5 for easy reference in the text.

II.3.1 Initial Stage

1) Fill apparatus with water and connect to a clean water supply.

2) Purge all air from the flow section (A) and from tubing to the transducer and inlet line. Close either valve A1 or A2.

3) Plug in apparatus to a 120v line.

4) Switch on C.D. demodulator (C1).

5) Connect voltmeter to the banana plug output terminals to the right of the C.D. demodulator (C4).

6) Set voltmeter range to 1 volt.

7) Open valve B2 and turn "zero" potentiometer C2 until the voltmeter reads 0.000.

8) Tilt the apparatus slightly. If the voltmeter varies more than ±0.010 volts then there is probably air in the transducer piping. This air must be removed before proceeding.

9) Open valve B1 and B3 and close valve B2. The voltmeter should still read 0.000 ± 0.010. If it does not, then there is likely air in the transducer lines or in flow section A.

10) Switch the selector valve B3 to its opposite position. Voltage should still be 0.000 ± 0.010. If not, there is likely air in the flow apparatus.

II.3.2 Transducer Calibrations

When data from the apparatus seem suspect during a test run (or at least once per year), the transducer calibration should be checked. Referring to Figure II-7, the procedure for the calibration is as follows:

1) Disconnect tubing from the transducer and reconnect the transducer to two water columns (manometer) with a centimeter scale.

2) Remove any air in the transducer lines or connecting tubing.

3) Close valve B1 and open valves B2 and B3.

4) Adjust "zero" potentiometer C2 until voltmeter reads 0.000.

5) Close valve B2 and open B1.

6) Add water to one side of the manometer until there is roughly 50 cm. differential in the two columns.

7) Read the exact differential in cm. (Call this value x).

8) Divide x by 5, yielding the expected voltage reading. If the actual voltage reading varies by more than 2% adjust the "span" potentiometer (3) until it reads x/5, then repeat steps 3) to 8)).

II.3.3. Check of Water Data

1) With the inlet of the screen apparatus connected to a (lightly) pressurized water supply, throttle flow through the apparatus.

2) Measure the pressure drop (voltages) through both the screen and venturi.

3) Repeat 2) for a range of flow rates.

4) Check data against previously established water data (Figure II-8).

5) If the data fall within ±20% of the earlier data then proceed. If not, then either the water is contaminated with polymer, the transducer span calibration C3 setting has been disturbed from its original 5.125 setting, or the appartus has been improperly assembled or the screens are damaged.

II.3.4 Data for Polymer Solutions

1) Connect inlet tubing of screen apparatus to an elevated reservoir of polymer solution, making sure that no air is trapped in the tubing.

2) Allow enough polymer solution to flow through flow apparatus A to completely displace the water ($\sim$ 1 litre)

or whatever liquid was in the system.

3) Repeat steps 1) to 3) of section 2.3.3.

II.3.5 Pump Venturi

In field applications when the polymer solution reservoir is not elevated, it may be necessary to draw the solution through the flow apparatus using a suction source. If there is no other available, the pump venturi may be used. Its installation is shown in Figure II-5. It should be used as follows:

1) Connect venturi to the outlet side of the apparatus.

2) Submerge the pump inlet (suction) into a water reservoir.

3) Plug in pump.

NOTE: DO NOT RUN THE PUMP DRY FOR MORE THAN 10 SECONDS.

II.4 Performance

The following section details the expected general behaviour of the instrument for both water and polymer solutions. It should serve as a reference for any water retests.

II.4.1 Data Presentation

The most convenient form for presenting data from the instrument data is a log-log plot of screen head loss Δh_s versus venturi head loss Δh_v. To relate the transducer voltage to pressure difference, the conversion factor is 5, i.e.,

differential head Δh(cm of water) = 5 x (voltage output).

Plotted in this way, most data will be linear.

II.4.2 Water Data

Data for water are shown in Figure II-8. The abscissa and ordinate values are given in volts, and heads in cm. can be obtained by multiplying these scales by 5.0. The various symbols represent data taken at different times.

II.4.3 Polymer Solutions

Data for various dilute solutions of polyacrylamide are presented in Part III. These data always lie above the values for water, and generally parallel to the water line. For concentrations up to 500 parts per million the shift in data may be as much as two orders of magnitude. Degraded solutions produce less effect than fresh ones.

PART III

TESTS OF FLOW INSTRUMENT AT WESTERN RESEARCH LABORATORY

The tests described in Part I of this report indicate that screen flow is an effective discriminator of polymer concentration and degradation. A final test program was undertaken to determine the extent to which these results would correlate with flocculating effectiveness. This section describes the tests carried out at WRL, between Feb. 10 and Feb. 24, 1982, to assess this correlation.

III.1 Scope

The three polyacrylamide samples tested in Part I were the same polymers used in the present work for comparative measurement of screen flow, intrinsic viscosity, flocculating effectiveness and molecular weight (light scattering).

John Saringer of the University of Toronto made measurements of screen flow while solution preparation, intrinsic viscosity measurement and light scattering tests were conducted by WRL.

Each polymer type was tested at several concentrations and at several stages of degradation.

III.2 Experimental Technique

III.2.1 Solution Preparation

Solutions were prepared by simply dispersing the polymer powder in filtered or distilled water. In some cases methanol was used to disperse the powder. No salts or acids

were used to control pH, nor were solutions filtered to remove aggregates.

III.2.2 Screen Tests

For each polymer, screen tests were conducted in increasing concentrations following the procedure recommended in Part II. Following experience gained from the U of T tests, the screens were cleaned regularly and particularly between tests of different types of polymer.

III.2.3 Flocculating Tests

These tests were conducted by dosing a 15% (by volume) clay suspension with a relatively concentrated polymer solution, i.e. with a concentration of 200-300 ppm. Maximum settling velocities were measured for several lower polymer concentrations. In these tests, concentrations were measured relative to the clay content of the suspension (i.e., parts of polymer per million of solids by weight and hence were independent of water content.

The method for adding concentrated polymer solution to the clay suspension proved to be quite critical. In the initial tests, single drops of the polymer solution were added and the resulting concentration calculated on the basis of an assumed drop size. Because drop size varied with concentration, it is not certain what the true polymer content was. Later tests, using a volumetric pipette for the injection of the polymer solution, produced more consistent results.

III.2.4 Viscosity Measurements

The viscosity of a test solution was measured by a precalibrated Canon-Fenske viscometer following standard procedures. Results from these tests were difficult to interpret because of inconsistency. It is speculated that impurities in the solutions or polymer aggregates may have been responsible for the anomalous results.

III.2.5 Light Scattering Measurements

Just before these tests were conducted at WRL, Raylo Chemicals experienced difficulty with their light-scattering equipment. Because these problems were not resolved until after the tests were completed, and because no other light-scattering equipment was available, this portion of the test program was deleted.

III.2.6 Solution Degradation

Solutions were degraded in several different ways, the most satisfactory of which was simple machine stirring. The other methods, by a pump or pump-nozzle combination, somehow created suspended debris in the polymer solutions. While this did not cause any difficulty with the screen tests (because of the upstream filter) it may have been the source of some difficulty in other tests. All of the later solutions were therefore degraded by the stirrer only. The stirrer, at its maximum speed of 1700 rpm, was run between 5 and 200 minutes to generate different levels of degradation.

III.3 Experimental Data

In the following section, data are presented for

screen flow, viscosity and flocculating velocity for each of the three polyacrylamide solutions (nonionic, anionic and cationic), at several concentrations and at different levels of degradation.

III.3.1 Screen Flows

III.3.1.1 Nonionic PAM

Figure III-1 is a plot of screen pressure drop vs. venturi pressure drop for water and 40, 80, 160 and 320 ppm solutions of the nonionic PAM. The results show a clear monotonic increase of non-Newtonian effect with concentration. The relative increase between concentrations decreases as the concentration increases, indicating that for this polymer it is easier to discriminate between the very dilute solutions (as low as 5 ppm). Conversely, this measurement technique is less useful for monitoring concentrations above 200 ppm.

Figure III-2 shows the results of relative pressure drops across the screen and venturi for water (solid line) and for fresh and degraded 320 ppm solutions of this polymer. As expected, the non-Newtonian effect diminishes as the amount of degradation increases.

III.3.1.2 Anionic PAM

Similar to the performance of the nonionic PAM, Figure III-3 shows a steady increase in non-Newtonian effect with concentration for the anionic polymer. Even more pronounced is the relative insensitivity of the measurements to concentration at higher concentrations, i.e. those above 100 ppm,

and the heightened sensitivity to concentrations below 20 ppm.

Figure III-4 presents the results for fresh and degraded samples of 160 ppm solutions of this polymer. As with the nonionic polymer, effects diminished in increasing level of degradation.

III.3.1.3 Cationic PAM

Unlike both the nonionic and anionic samples, data for the cationic polymer (Figure III-5) shows evenly spaced increases of non-Newtonian effect independent of concentration over the range from 20 to 320 ppm tested. There is no concentration range for which the measurements are particularly sensitive or vice versa. Like both the neutral and anionic solutions, consistent decreases of effect were observed for increased degradation (Figure III-5).

III.3.1.4 Discussion

In comparison with the preliminary tests conducted at the University of Toronto, polymer effects obtained at WRL were larger, indicating much greater sensitivity of the measurement technique than anticipated. This, of course, makes the instrument more useful. That is, even errors as much as ± 50% in measurement would be negligible because polymer data were typically 500% to 10,000% above those for water.

The reason for the discrepancy between WRL and U of T data probably lies in the solution preparation technique. At the U of T, salts were added to buffer the solutions, and

this has the effect of collapsing the polymer coils and thus reducing non-Newtonian effects. While this buffering was desirable to yield reproducibility in the solutions — and is thus suitable for laboratory purposes — not buffering the solutions is more typical of industrial applications.

Similar to results obtained at the U of T, the degraded solutions tested at WRL showed decreases of non-Newtonian effects for increased amounts of degradation. Also, there was an apparently larger drop in effect at higher flow rates than at lower ones, suggesting that measurements of degradation are best conducted at high flow rates.

III.3.2 Viscosity Data

Figures III-6, III-7 and III-8 show reduced viscosity data for the nonionic, anionic and cationic polymers respectively. These measurements were made with the expectation that a degraded solution would exhibit a reduced intrinsic viscosity, and that the relative drop would be a measure of degradation. For the nonionic sample, data for the degraded solutions were evidently not reproducible because of the large amount of scatter. In the case of the anionic polymer, the reduced viscosity falls as a function of concentration for the fresh solution, which is not normal, and no degraded samples were tested because they were apparently mislaid. In the case of the cationic polymer, a reduced viscosity was observed for the degraded solution but the history of this solution, including its degree of degradation, was unknown. In view of the anomalous results for both the nonionic and anionic polymer solutions, the cationic polymer results may

not be reliable. As mentioned in Viscosity Measurements, the likely source of error in these measurements was the method of solution preparation.

III.3.3 Flocculating Data

Flocculating data were obtained for both fresh and degraded samples with the expectation that the flocculating velocities would be reduced when the seeding polymer solution was degraded. From Tables III-9, III-10 and III-11, there is some evidence of this behaviour but the inconsistency in Table III-10b, where a degraded solution has produced higher setting velocities than a fresh solution, combined with the observed large difference of setting rate in the first three columns of Tables III-9, (which should have been roughly equal), casts doubt on the remaining data. These results, regrettably, cannot be used to draw conclusions.

REFERENCES

1. Batycky, J.P. and Masata, V.K., "Polymer Solution Degradation and the Meaning of Screen Factor," Petroleum Recovery Institute Research Report RR-39, Calgary, Alberta, 1978.

2. MacWilliams, D.C., Rogers, J.H. and West, T.J., "Water-Soluble Polymers in Petroleum Recovery" in T.M. Bikales (Ed.), "Water-Soluble Polymers," Plenum Press, N.Y., 1973.

3. Jennings, R.R., Rogers, J.H. and West T.J., "Factors Influencing Mobility Control by Polymer Solutions," J. Pet. Tech., Vol. 23, p. 391, 1971.

Appendix

The Research Proposal by Professor D.F. James

submitted to the Ministry of Energy, Mines and Resources

UNSOLICITED PROPOSAL

SCREEN FLOW – A MEANS OF MONITORING THE FLOCCULATING EFFECTIVENESS OF A POLYMER SOLUTION

A proposal to the Ministry of Energy, Mines and Resources for a feasibility study

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INTRODUCTION

High molecular weight polymers are used as additives in a number of flow processes: for example, to coagulate and flocculate particles in sedimentation, to thicken water in secondary oil recovery, and to reduce friction in turbulent pipe flow. In each situation, the amount of polymer required is very small, generally around 5 to 500 parts per million by weight. At these concentrations, it is difficult to characterize a solution — i.e. to predict its effectiveness in a particular application — , and this proposal focusses on a means of overcoming some of the difficulties.

One difficulty is that measurement of polymer properties related to performance requires expensive instrumentation and time-consuming techniques. The effectiveness of a polymer in any of the above applications depends on its mean molecular weight, molecular weight distribution, ionic charges, solvent affinity (which determines the size of the molecular coil), and on solution pH. Each factor can be measured with available instrumentation, but often the equipment is costly and the process lengthy, eg., the light-scattering apparatus required for molecular weight and coil size.

The second difficulty is that, while polymer effectiveness is related to the above properties, knowledge of these properties is not sufficient to predict performance. That is, the effect of polymeric additive on a flow depends not only on the above molecular properties but also on solvent viscosity, solute-solvent friction, molecular aggregation and so on. Each parameter

influences the flow dynamics and each can be measured individually; however, it would be more appropriate to assess their combined effect by the measurement of a single hydrodynamic property. This single property will be termed 'hydrodynamic resistance', and it is this property which governs molecular diffusion and therefore viscous effects in a flowing solvent. Because this property is an overall measure of the additive, it takes into account solution characteristics as well as molecular properties; in particular, it accounts for molecular aggregation, as found in freshly-prepared solutions, and for degradation, as found in aged or highly-strained solutions.

This key property cannot be measured in standard viscometric flows like shear flow. In tube flow, for example, a dilute polymer solution behaves essentially as a simple Newtonian fluid, with a shear viscosity higher than that of the solvent. In an elongational flow, however, the extensional viscosity of the solution may be a thousand times that of the solvent. This high extensional viscosity has been identified as the fluid property which is responsible for the increased hydraulic resistance in porous media flow and for the reduction of friction in turbulent pipe flow. It is likely an essential property for sedimentation as well, although this has not yet been proven. Hence the property hydrodynamic resistance is very closely related to extensional viscosity. Two flows that depend directly on extensional viscosity, and therefore provide a measure of hydrodynamic resistance, are flow through a small orifice and flow through a fine screen, such as the wire-woven types available commercially. We have conducted preliminary studies with such screens and the results indicate that this flow is a sensitive monitor of solution and molecular properties. These initial studies are described next.

PRELIMINARY STUDIES ON SCREEN FLOW

During the past two years, we have investigated the flow of dilute aqueous solutions of polyethylene oxide through wire-woven screens, and the results show that the resistance to flow depends markedly on solution characteristics. The general pattern is that, at very low flow rates, the pressure drop across the screen for a dilute solution is virtually the same as for water, but that at a sufficiently high velocity, the flow resistance rises above the values for water, and at larger velocities, the resistance is two to five times higher than for water. This large change in resistance occurs for very dilute solutions – around 20 parts per million (our polymers had molecular weights around 5×10^6). These studies were carried out over a range of screen sizes, flow rates and polymer concentrations, and with fresh and degraded solutions. It appears that maximum flow resistance is a good measure of a solution's overall hydrodynamic resistance and that onset of non-Newtonian behaviour depends essentially on polymer molecular weight and not on concentration. Because of the latter effect, the screen is a sensitive monitor of degradation.

The flow characteristics described here are very similar to the behaviour of dilute polymer solutions in a porous medium; thus a screen flow, which is relatively simple, can also serve as a model for the testing of polymers used in polymer flooding.

PROPOSED RESEARCH PROGRAM

Our initial studies were actually part of a fundamental study on the configuration of long-chain molecules in extensional flow. Since these studies have shown also that screen flow is particularly sensitive to solution properties, it is proposed that a separate research program be undertaken to ascertain whether screen flow might serve as a useful monitor of flocculating efficiency. That is, it is anticipated that the flow resistance of a polymer solution through a screen, under certain conditions, might correlate with the solution's ability to settle out suspended particles. The appropriate conditions would have to be found by extensive testing and it is proposed that the initial test program be carried out in two stages, as follows:

STAGE 1: Feasibility Study and Design of Flow Instrument

This part of the program would be carried out in the Department of Mechanical Engineering, University of Toronto.

a) Polymers with well-established flocculating characteristics would be tested in a flow cell containing a screen. Western Research Labs (CANMET) would supply the test polymers — perhaps four different types and two molecular weights of each.

b) Solutions of each polymer would be tested for flow resistance at various concentrations, with different screens and over a range of flow rates. About 60 tests in all would be necessary to establish the flow resistance characteristics for the eight polymers.

c) The flow tests would also include solutions which had been degraded by pump shearing or ultrasound.

d) The flow data would be thoroughly analyzed to ascertain (i) to what degree flow resistance correlates with a polymer's known flocculating capability, (ii) under what conditions the correlation is best.

e) From the conditions of d(ii), a flow device would be designed and built, suitable for monitoring flocculating in a laboratory setting. The flow device would comprise a test cell with a screen, a fluid supply system, and instrumentation to measure flow rate and pressure drop across the screen.

STAGE 2: Evaluation of Flow Instrument as a Monitor of Flocculating Efficiency

a) The device built in STAGE 1 would be tested at WRL, Edmonton, with actual flocculating solutions. A variety of polymer solutions would be tested (i) for flocculating efficiency by the usual methods and (ii) for hydrodynamic resistance in the new flow device. The tests, taking about two weeks, would be sufficiently extensive to clearly establish the degree of correlation between the two parameters.

b) A report would be prepared describing the tests and results. The report would be in the form of a paper suitable for publication in a good technical journal, and would be presented as a joint project of WRL and the U. of T.

Hopefully the test program would lead to the design of a prototype flow device, suitable for laboratory or field tests, to monitor the effectiveness of a flocculent.

BUDGET

The proposed program is expected to take 8 months to complete, starting in April, 1981. The costs are as follows:

Personnel:	
David F. James, Principal Investigator	$ 3,600.
John H. Saringer, Research Associate	$ 5,900.
Technician, unnamed	$ 4,000.
Equipment:	$ 2,300.
Travel: D.F. James	$ 1,200.
Laboratory Trials (Edmonton): J.H. Saringer	$ 1,300.
	$18,300.
Overhead (University of Toronto presently charges 30% on contracts)	$ 7,840.
Total Cost	$26,140.

Notes:

All personnel work part-time on this project.

Principal Investigator - responsible for overall management of proposal, negotiation, supervision of tests and interpretation of results.

Research Associate - responsible for day-to-day supervision of the project; aids in concept, design, and data interpretation; conducts flow tests at WRL, Edmonton.

Technician - works under research associate, runs apparatus and obtains data.

Equipment - pressure transducer and associated electronics, flow measuring equipment, test section material.

Travel - for D.F. James to WRL (Edmonton), EMR (Ottawa) and a technical conference.

Laboratory Trials - costs for J.H. Saringer to spend 2 weeks at WRL, Edmonton.

Proposed Budget for Research Contract
Screen Flow – A Means of Monitoring the
Flocculating Effectiveness of a Polymer Solution

1.	Salaries	
	i) D.F. James, Ph.D., P.Eng. Principal Investigator 16 days @ $215/day	$ 3,440
	ii) John Saringer Research Engineer	
	a) 38 days @ $120/day	4,560
	b) 10 days @ $120/day	1,200
	iii) Technician, TBA 48 days @ $90/day	4,320
	iv) Workshop Services: For machining and fabrication of equipment 180 hrs. @ $15/hr.	1,500
	v) Secretarial and Administrative 16 days @ $79.06/day	1,265
	Total Salaries	$16,285
2.	Supplies & Disbursements	1,000
3.	Equipment	
	Pressure transducer and associated electronics, flow measuring equipment, test section material	1,300
4.	Travel	
	i) D.F. James To WRL, Edmonton, EMR, Ottawa, and a Technical Conference	1,200
	ii) John Saringer Two weeks at WRL, Edmonton – for trial tests	1,300
5.	Overhead	
	30% of 1(i),(ii)(a),(iii),(iv),(v),2	4,825
	15% of 1(ii)(b)	180
	0% of 3	ø
	2% of 4	50
	Total Budget	$26,140

S.K. Mehta
Administrative Officer

D.F. James
Principal Investigator

R.D. Venter
Chairman

81-08-26

RESEARCH PERSONNEL

The personnel suggested for this research proposal have considerable experience with non-Newtonian fluids:

David F. James, Principal Investigator:
(a Curriculum Vitae is attached)

- Professor of Mechanical Engineering at the University of Toronto, a specialist in fluid mechanics;
- has worked on the flow of polymer solutions since 1965 and has published extensively in this field; is probably the most experienced researcher in this field in Canada.
- in recognition of the quality of his research on non-Newtonian flow, was awarded the Commonwealth Fellowship at St. John's College, Cambridge, 1974-75.
- visited Western Research Laboratory in February, 1980, to present a seminar and to discuss sedimentation techniques and problems;

John H. Saringer, Research Associate:

- graduated from the University of Toronto in 1977 in Mechanical Engineering, and is presently a Ph.D. student at McMaster University;
- started working in 1975 for Professor James as a part-time Research Assistant, and has become increasingly involved in the polymer research program to the point that he is now a Research Associate in the Department of Mechanical Engineering.
- is the co-author, with Professor James, of several papers on the flow of dilute polymer solutions.

INITIAL SETTLING RATE (CM/HR) OF

NONIONIC POLYMER

CONCENTRATION (ppm)	DOSE (ppm)							
	5	10	15	20	25	30	35	40
40	0	70	137	240	337	385	431	466
80	0	67	152	265	327	400	420	435
320	73	205	347	529	595	599	599	575
320 (20 mins deg)	58	134	272	377	496	510	518	508
320 (40 mins deg)	58	103	187	289	367	448	446	479
320 (Pump and nozzle)	48	68	95	123	189	286	316	328

TABLE III-9

#1 INITIAL SETTLING RATE (CM/HR) OF

ANIONIC POLYMER

CONCEN-TRATION (ppm)	DOSE (ppm)							
	5	10	15	20	25	30	35	40
20	70	220	488	741	771	853	1056	1167
40	61	161	348	505	576	596	656	831
80	55	147	334	501	568	622	703	607
160	66	189	445	562	656	706	740	686

TABLE III-10a)

#2 INITIAL SETTLING RATE (CM/HR) OF

ANIONIC POLYMER (PREP'D FEB. 23/82)

CONCEN-TRATION (ppm)	DOSE (ppm)							
	5	10	15	20	25	30	35	40
160	56	137	216	342	393	391	463	486
160 (deg)	85	205	378	507	645	498	627	658

TABLE III-10b)

#3 INITIAL SETTLING RATE (CM/HR) OF ANIONIC POLYMER (PREP'D MAR. 1/82)

CONCENTRATION (ppm)	DOSE (ppm) 5	10	15	20	25	30	35	40
160	92	260	434	444	465	478	465	478
160 (degraded 3 hr. stirring)	107	185	251	268	279	279	301	297

TABLE III-10c)

INITIAL SETTLING RATE (CM/HR) OF

CATIONIC POLYMER

CONCEN-TRATION (ppm)	DOSE (ppm) 5	10	15	20	25	30	35	40
20	33	47	71	126	195	244	273	303
320	36	52	77	140	213	311	381	404
320 (15 mins deg)	43	60	78	110	150	182	193	229
320 (3 hrs. deg)	33	50	66	81	96	111	126	152

TABLE III-11

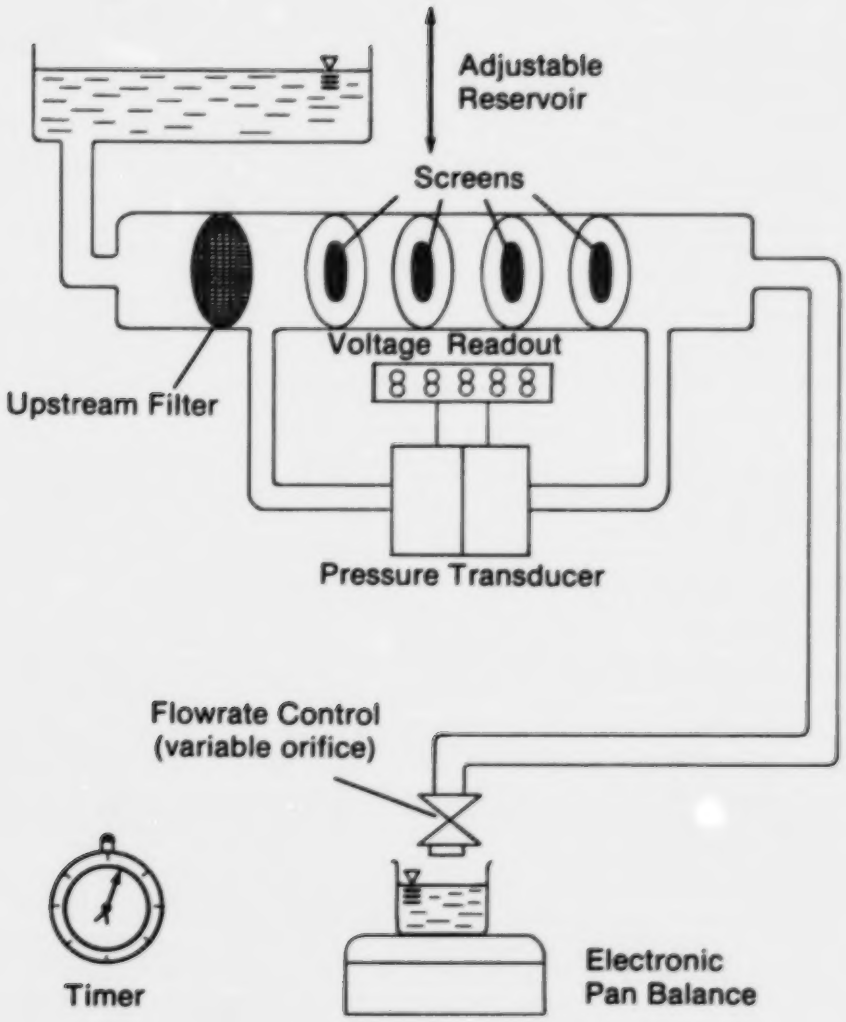


Figure I-1 FLOW APPARATUS FOR THE LABORATORY SCREEN TESTS

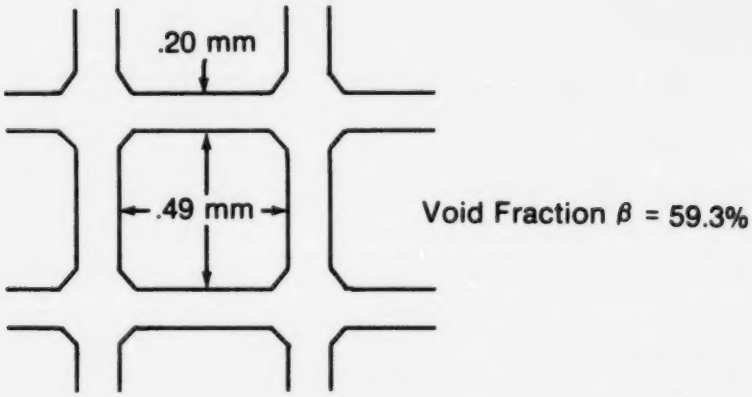


Figure I-2 GEOMETRY OF THE SCREEN MATERIAL, MADE FROM HEADS OF ELECTRIC SHAVERS

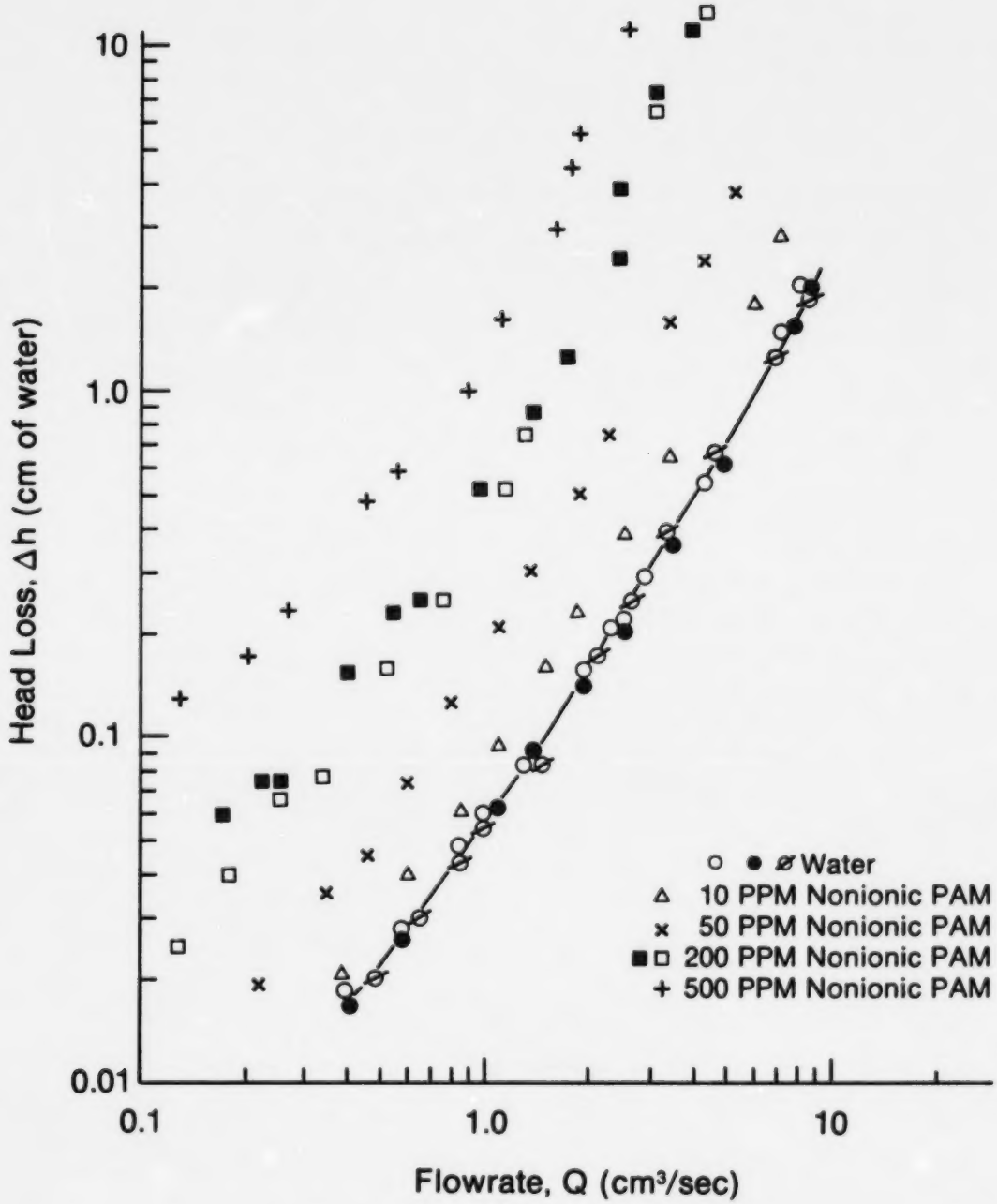


Figure I-3 HEAD LOSS THROUGH THE SCREENS FOR WATER AND VARIOUS CONCENTRATIONS OF NONIONIC PAM

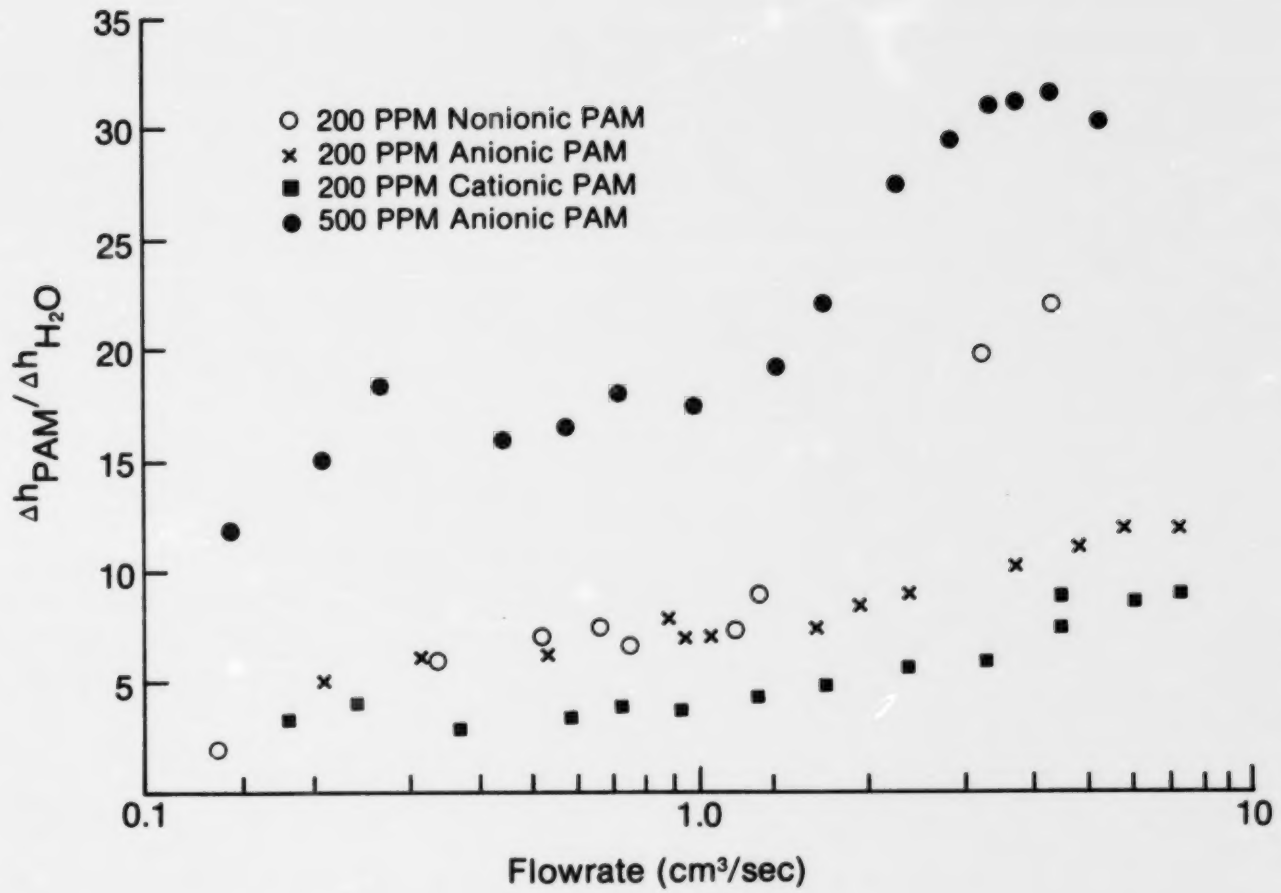


Figure I-4 THE HEAD LOSS OF A PAM SOLUTION, RELATIVE TO THAT FOR WATER, FOR THE THREE PAM SAMPLES

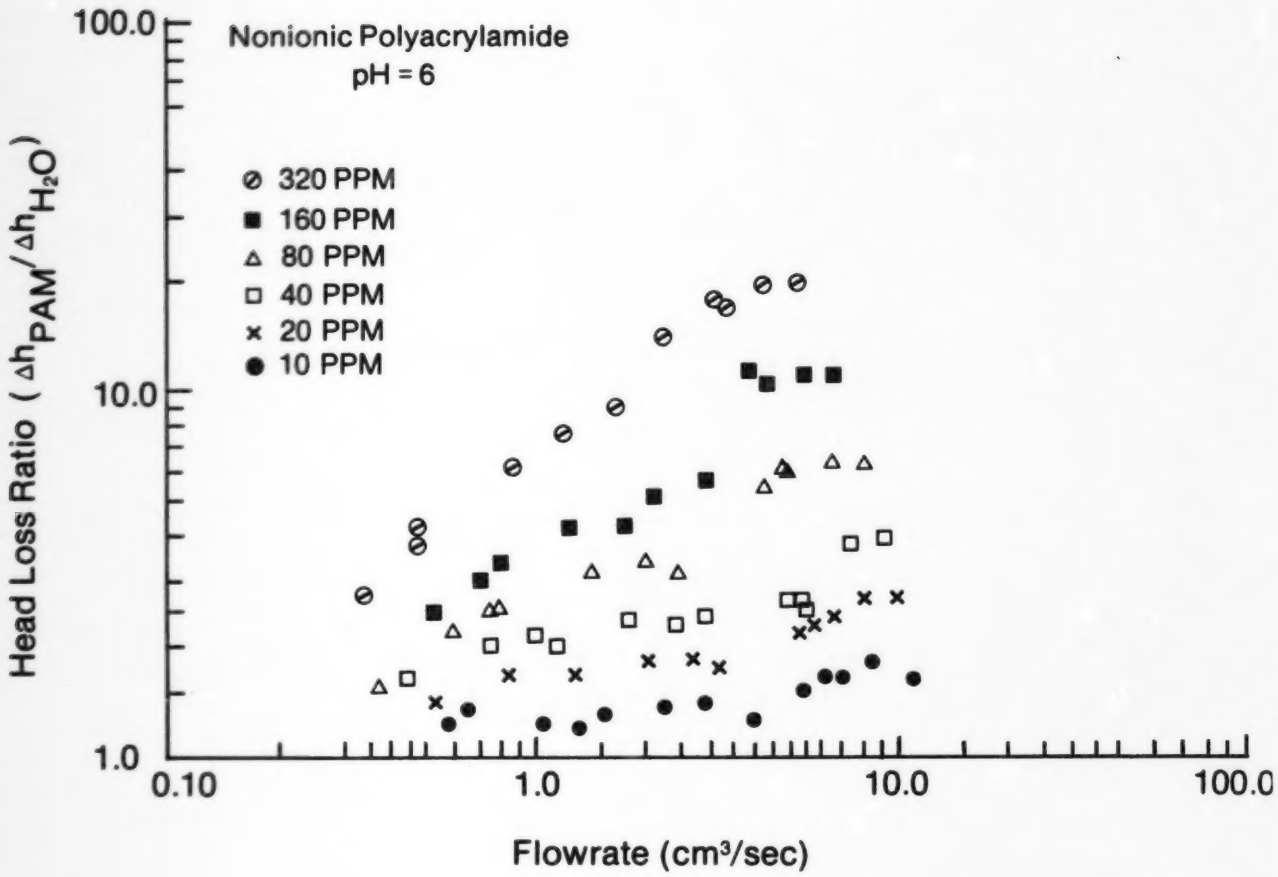


Figure I-5 RELATIVE HEAD LOSS ACROSS THE SCREENS FOR 6 CONCENTRATIONS OF THE NONIONIC PAM

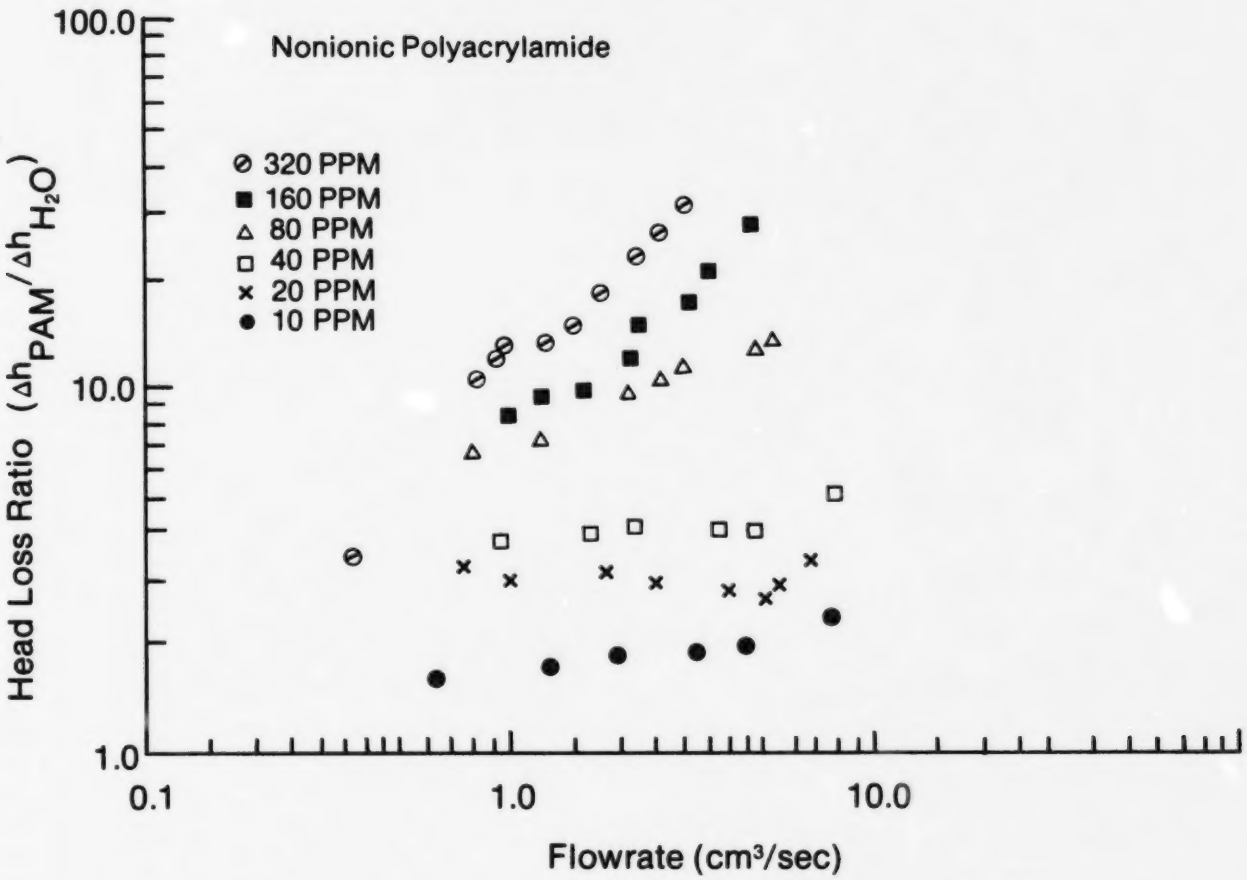


Figure I-6 RELATIVE HEAD LOSS ACROSS THE SCREENS FOR 6 CONCENTRATIONS OF THE NONIONIC PAM

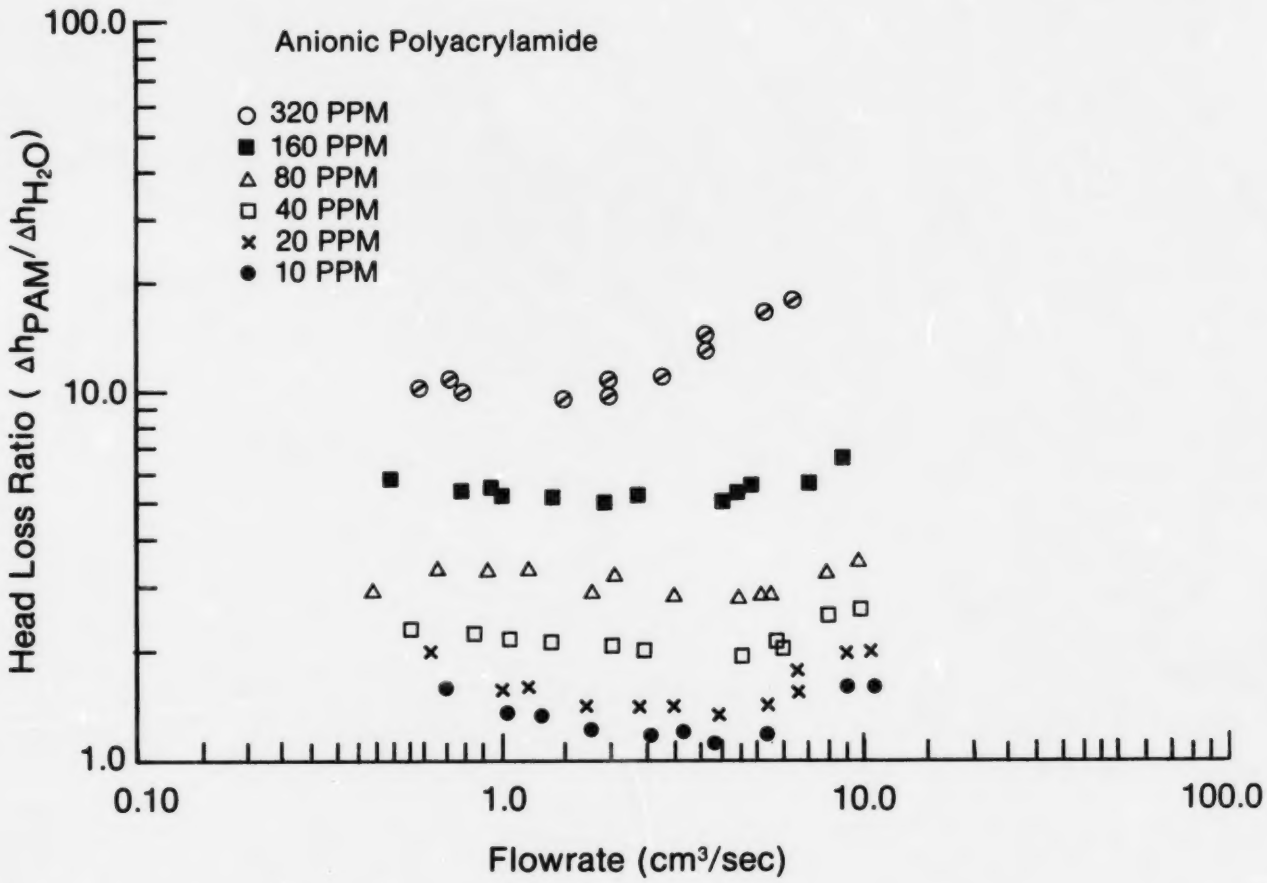


Figure I-7 RELATIVE HEAD LOSS ACROSS THE SCREENS FOR 6 CONCENTRATIONS OF THE ANIONIC PAM

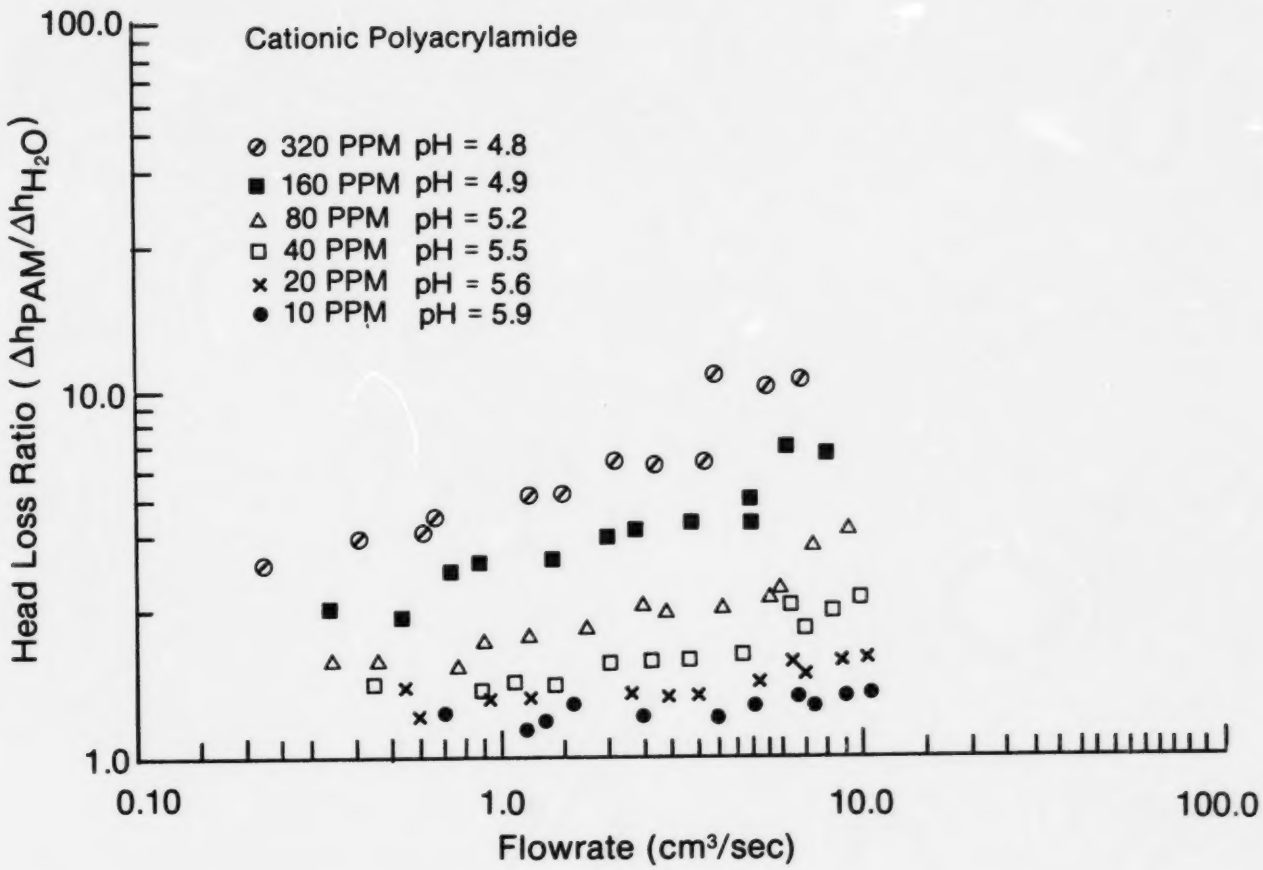


Figure I-8 RELATIVE HEAD LOSS ACROSS THE SCREENS FOR 6 CONCENTRATIONS OF THE CATIONIC PAM

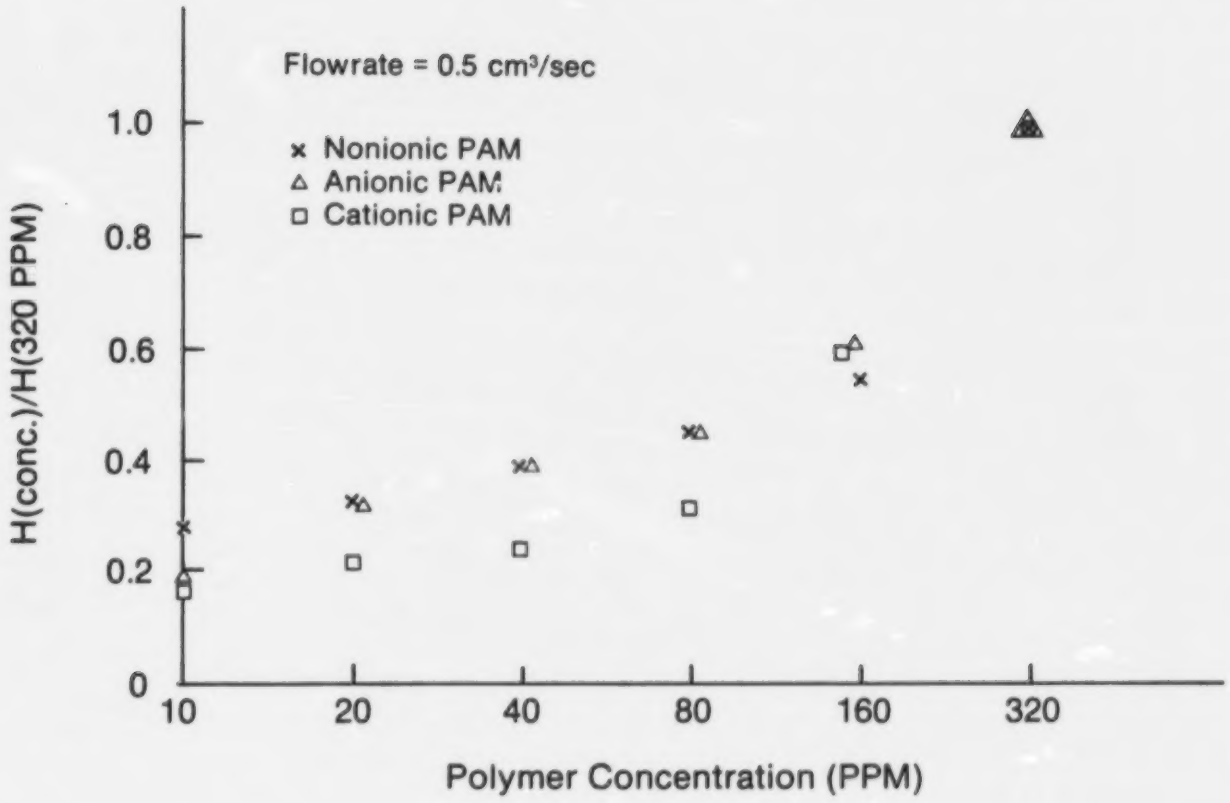


Figure I-9 THE HEAD LOSS RATIO, NORMALIZED TO 320 PPM, FOR ALL 3 POLYMERS AT 0.5 cm³/sec. DATA FROM FIGURES 5 TO 8.

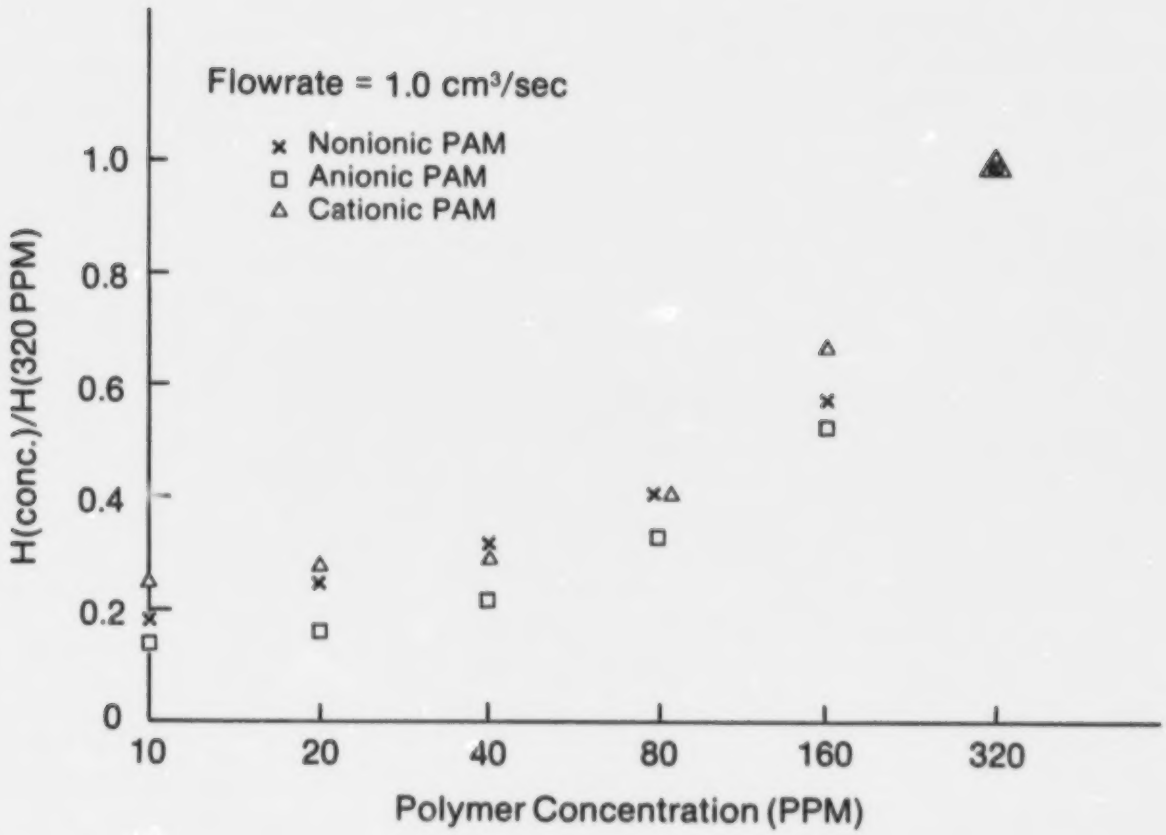


Figure I-10 THE HEAD LOSS RATIO, NORMALIZED TO 320 PPM, FOR THE 3 POLYMERS, AT 1.0 cm³/sec. DATA FROM FIGURES 5 TO 8.

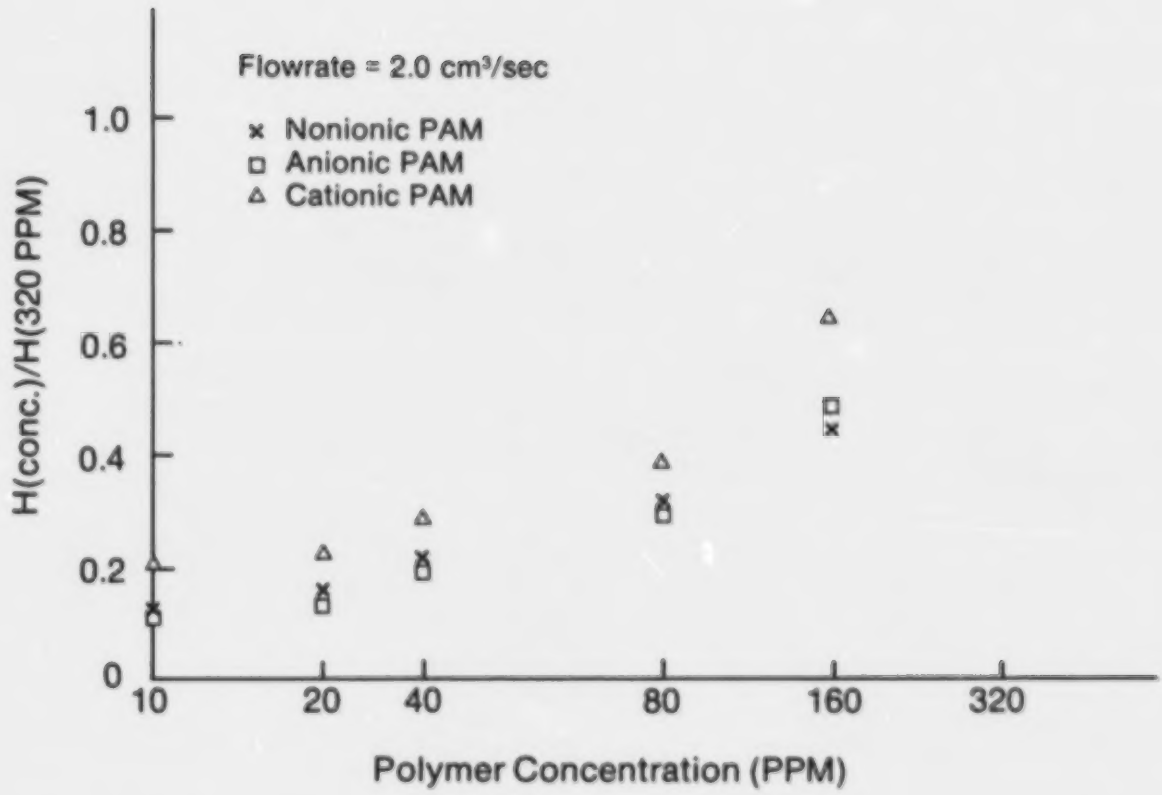


Figure I-11 THE HEAD LOSS RATIO, NORMALIZED TO 320 PPM, FOR ALL 3 POLYMERS AT 2.0 cm³/sec. DATA FROM FIGURES 5 TO 8.

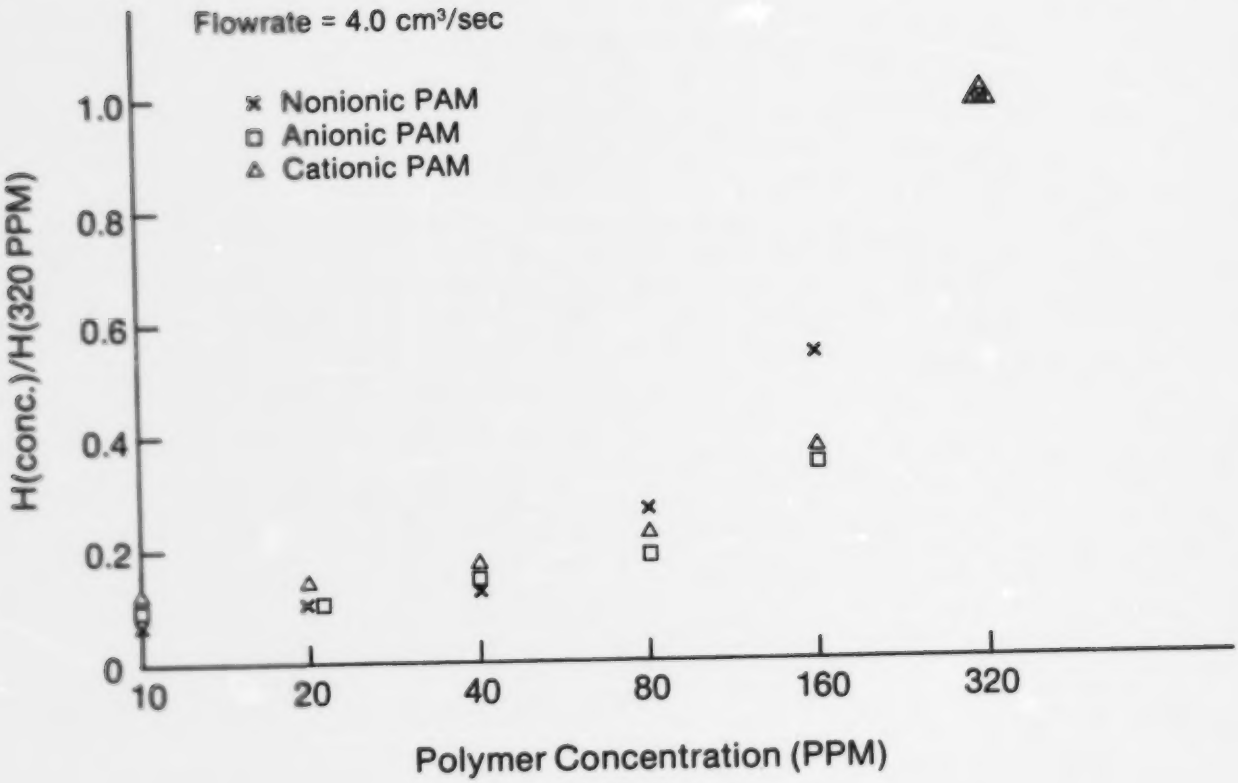


Figure I-12 THE HEAD LOSS RATIO, NORMALIZED TO 320 PPM, FOR ALL 3 POLYMERS AT 4.0 cm³/sec. DATA FROM FIGURES 5 TO 8.

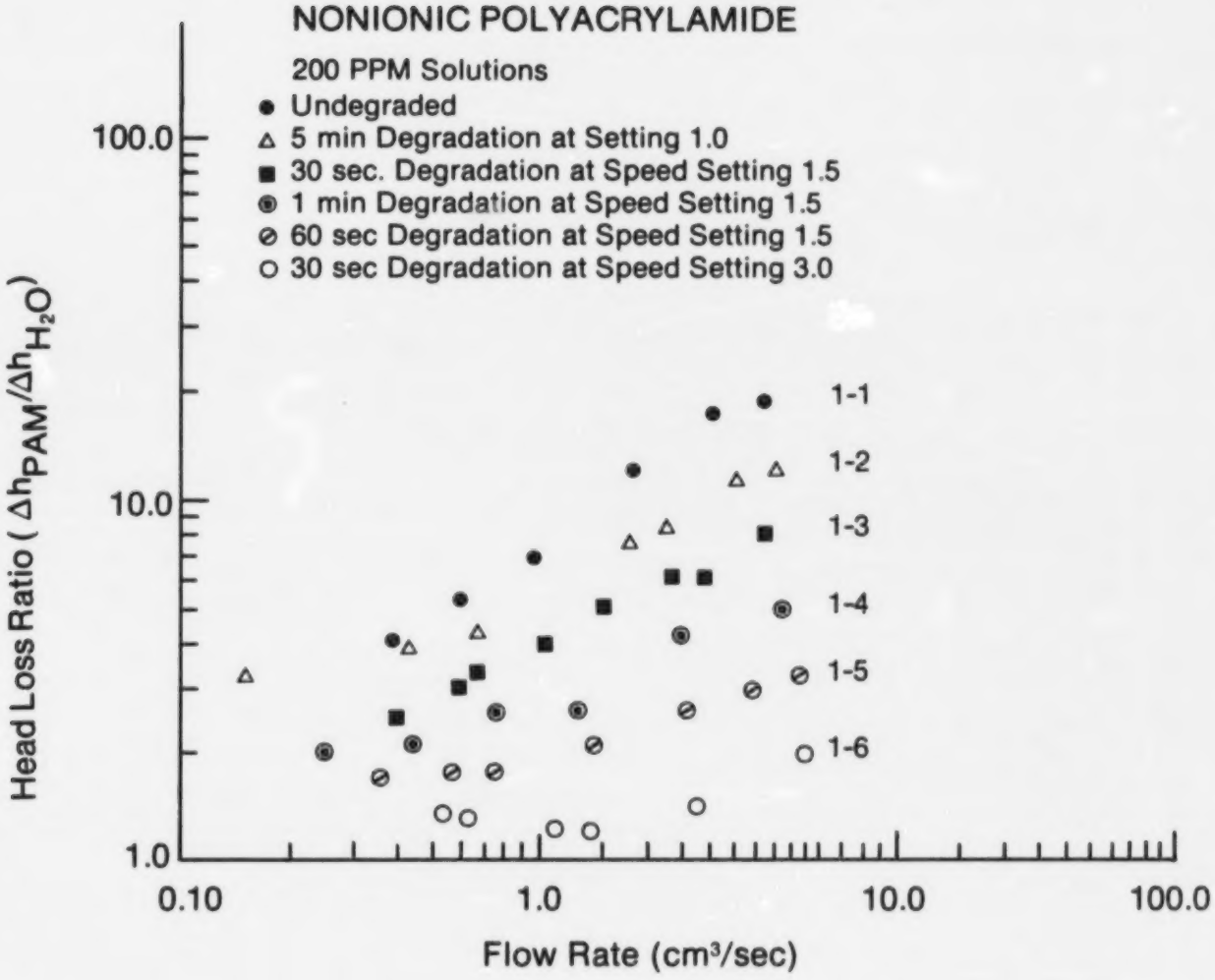


Figure I-13 HEAD LOSS RATIO OF DEGRADED SOLUTIONS OF 200 PPM NONIONIC PAM

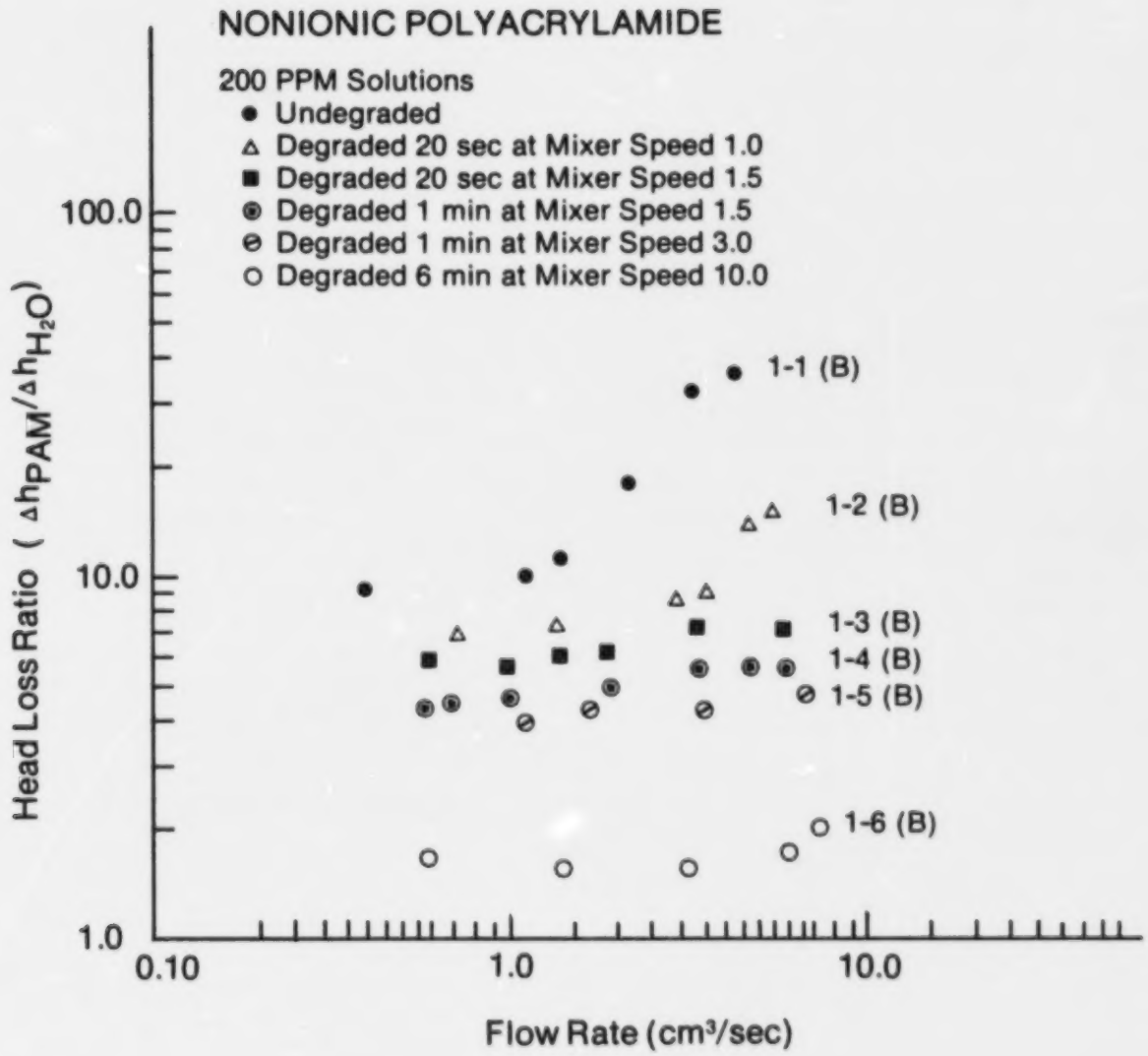


Figure I-14 HEAD LOSS RATIO FOR DEGRADED 200 PPM SOLUTIONS OF NONIONIC PAM

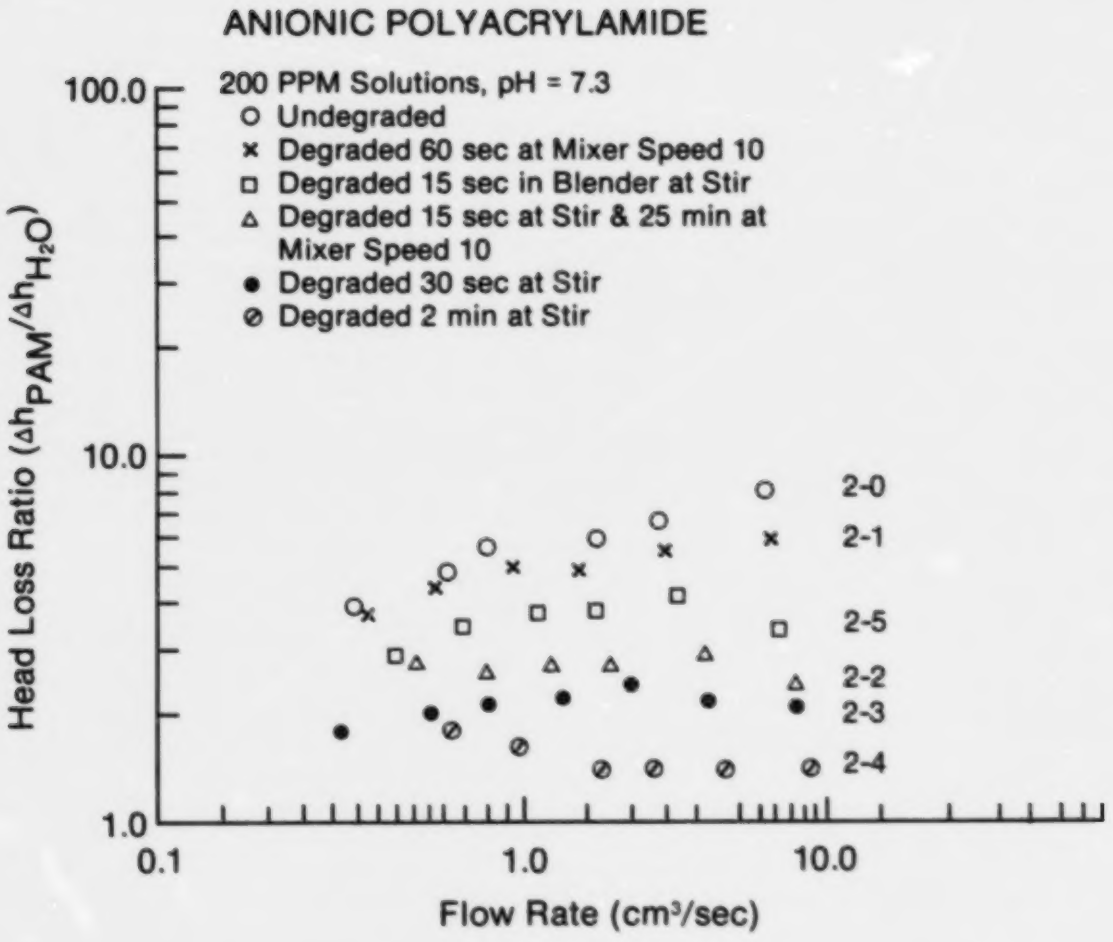


Figure I-15 HEAD LOSS RATIO FOR DEGRADED 200 PPM SOLUTIONS OF ANIONIC PAM

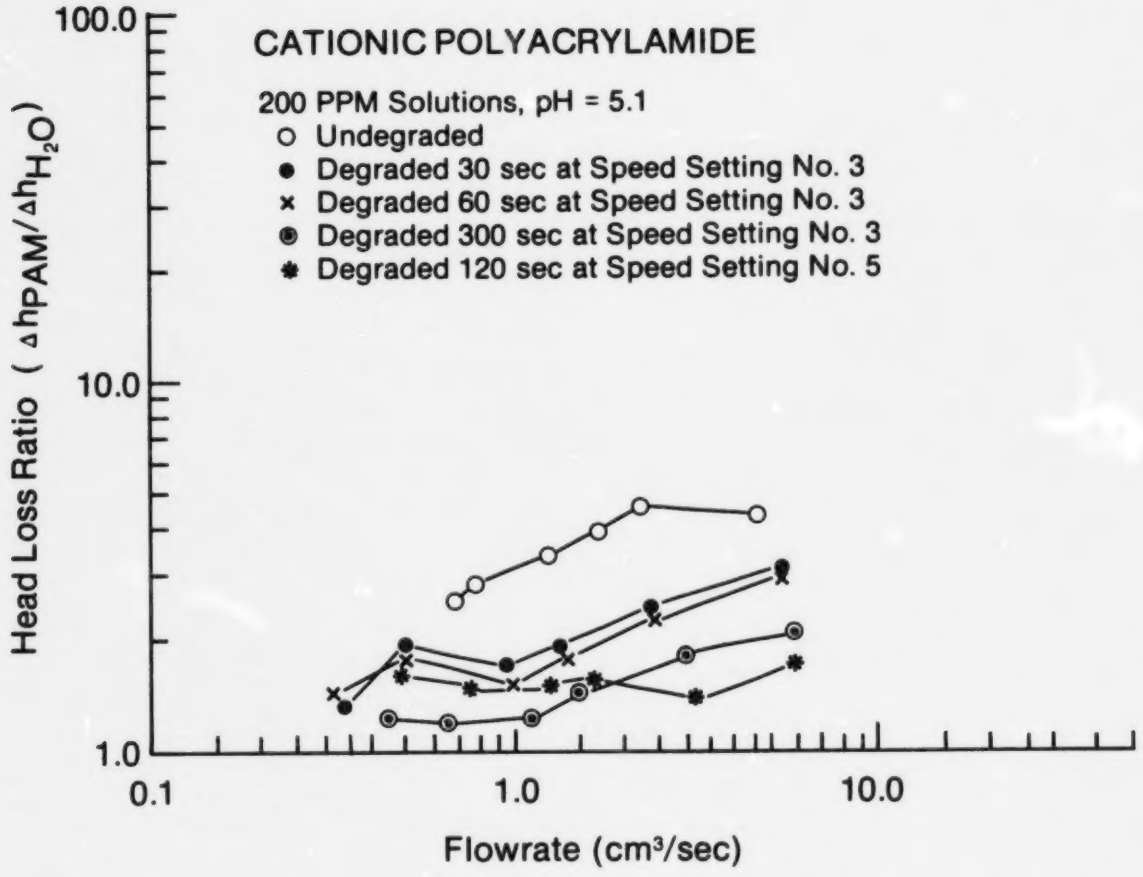


Figure I-16 HEAD LOSS RATIO FOR DEGRADED 200 PPM SOLUTIONS OF CATIONIC PAM

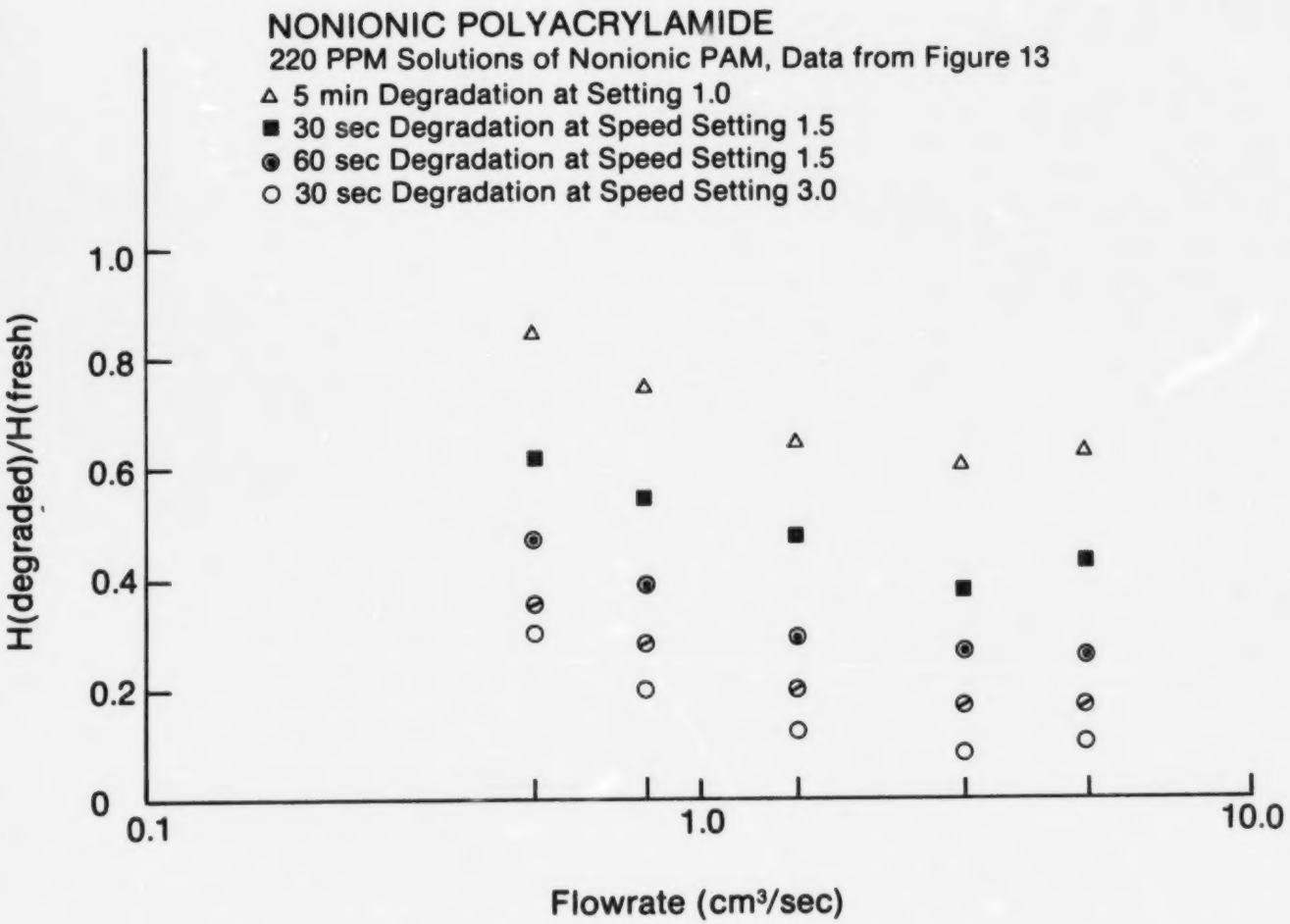


Figure I-17 HEAD LOSS RATIO OF A DEGRADED 200 PPM SOLUTION, RELATIVE TO A FRESH ONE, FOR THE NONIONIC PAM

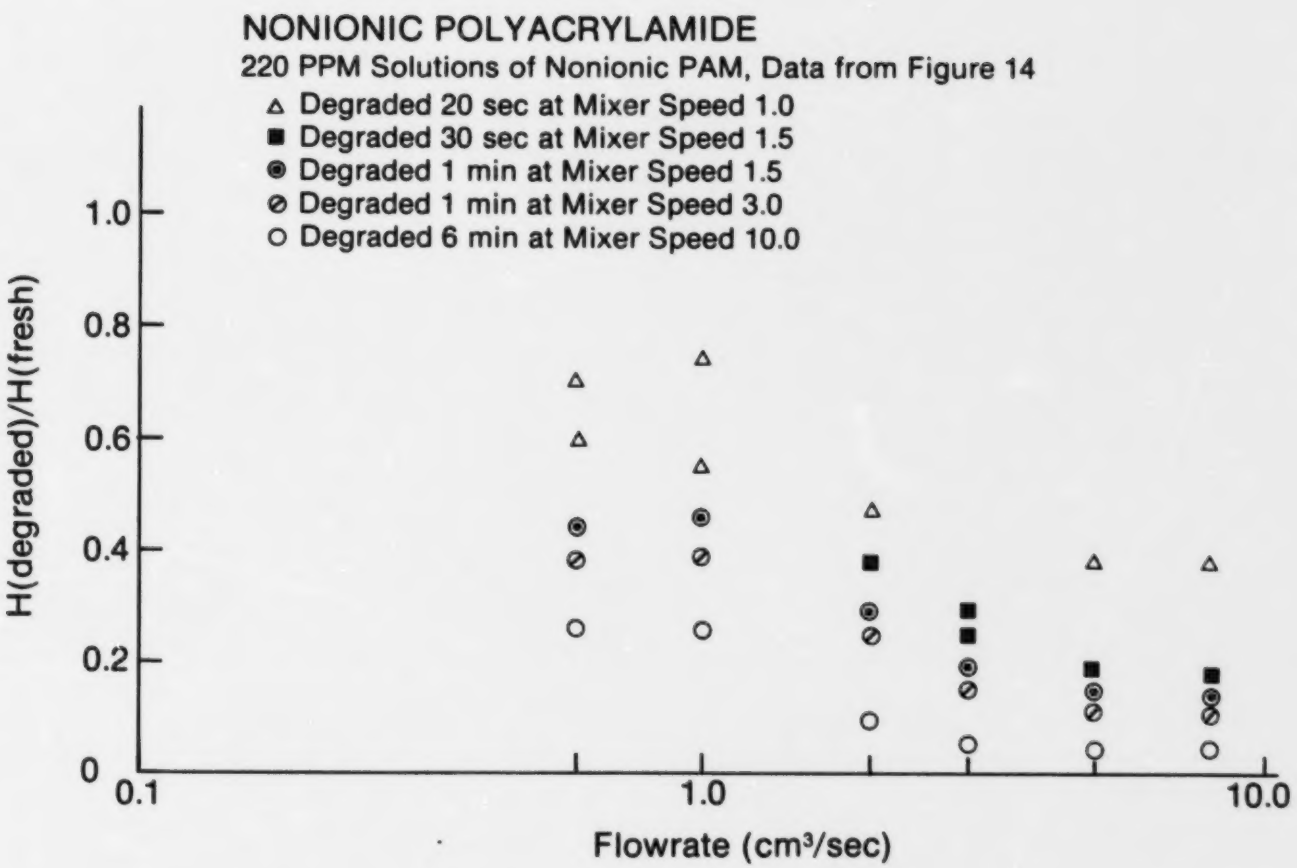


Figure I-18 HEAD LOSS RATIO OF A DEGRADED 200 PPM SOLUTION, RELATIVE TO A FRESH ONE, FOR THE NONIONIC PAM

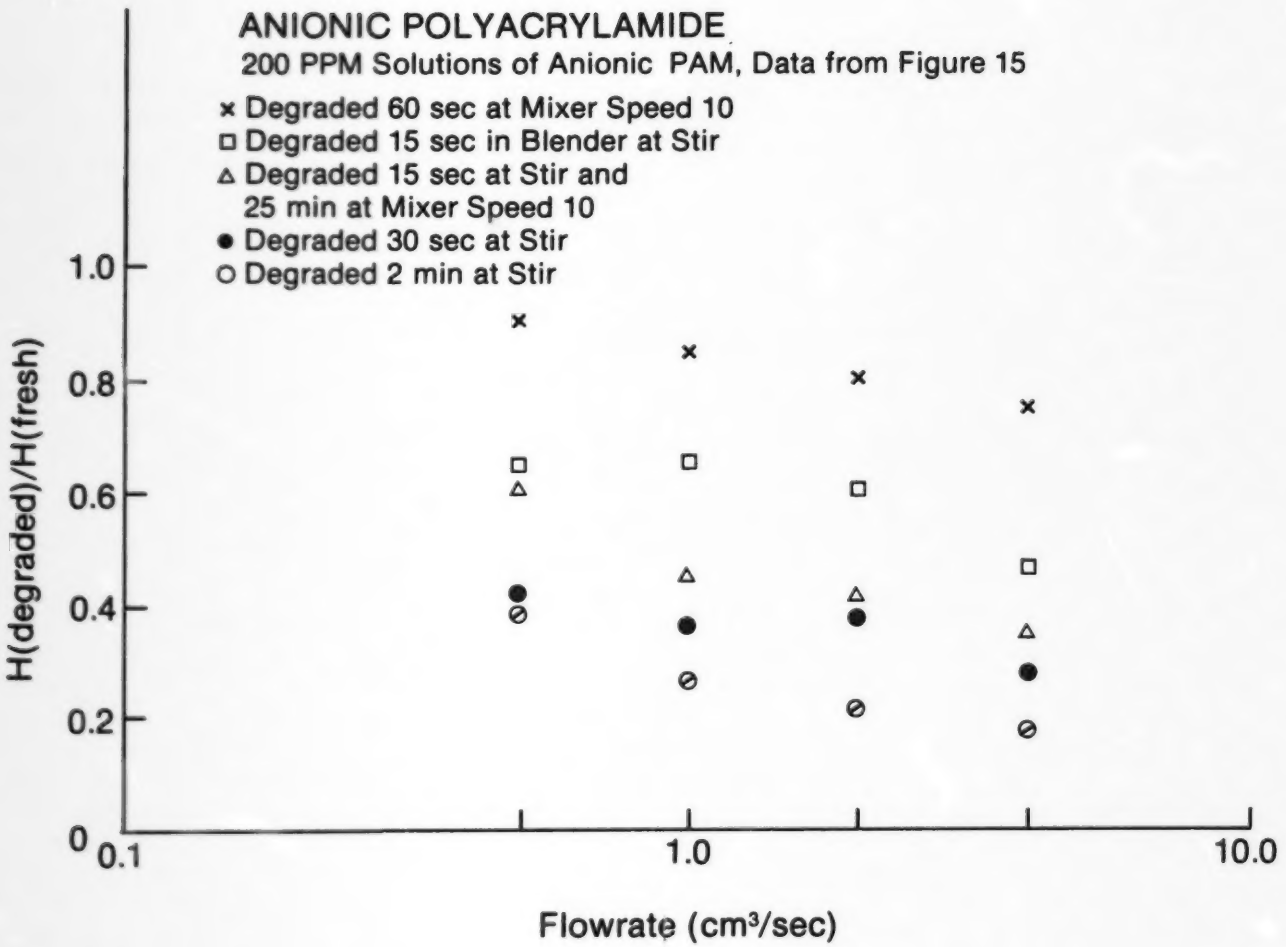


Figure I-19 HEAD LOSS RATIO OF A DEGRADED 200 PPM SOLUTION, RELATIVE TO A FRESH ONE, FOR THE ANIONIC PAM

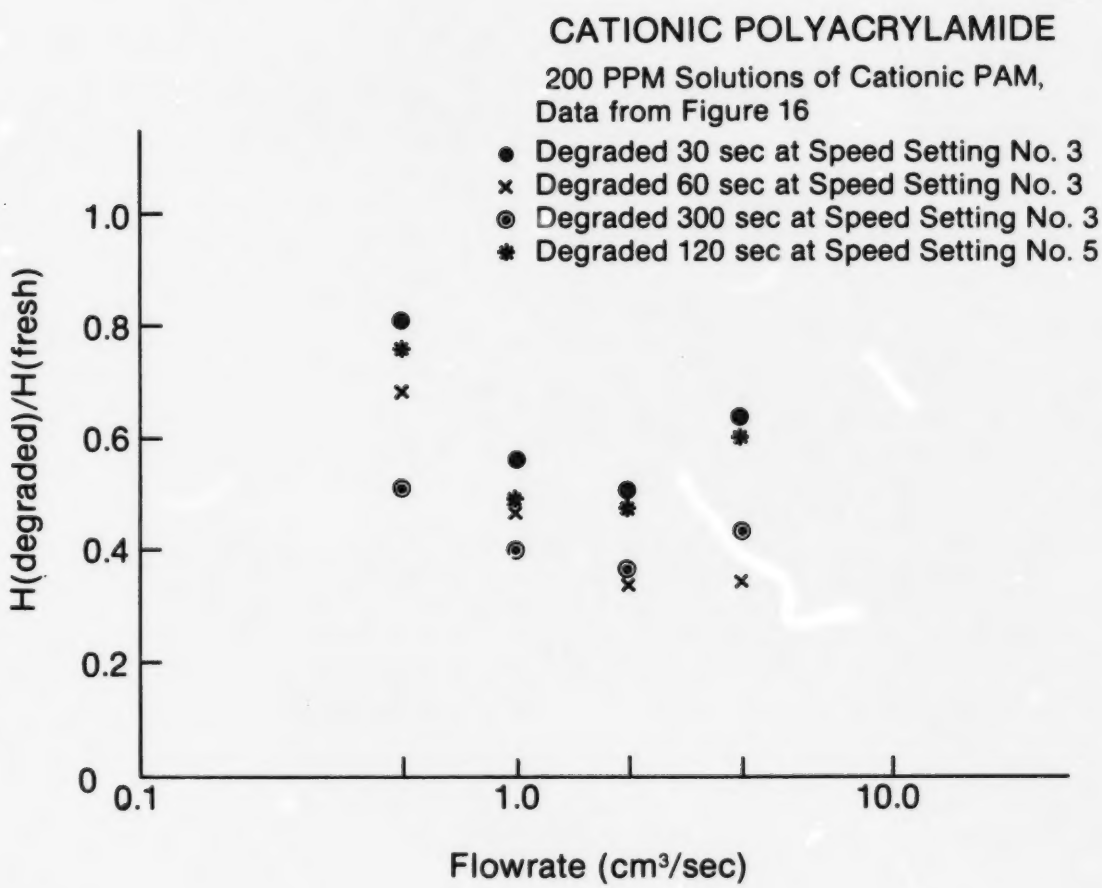


Figure I-20 HEAD LOSS RATIO OF A DEGRADED 200 PPM SOLUTION, RELATIVE TO A FRESH ONE, FOR THE CATIONIC PAM

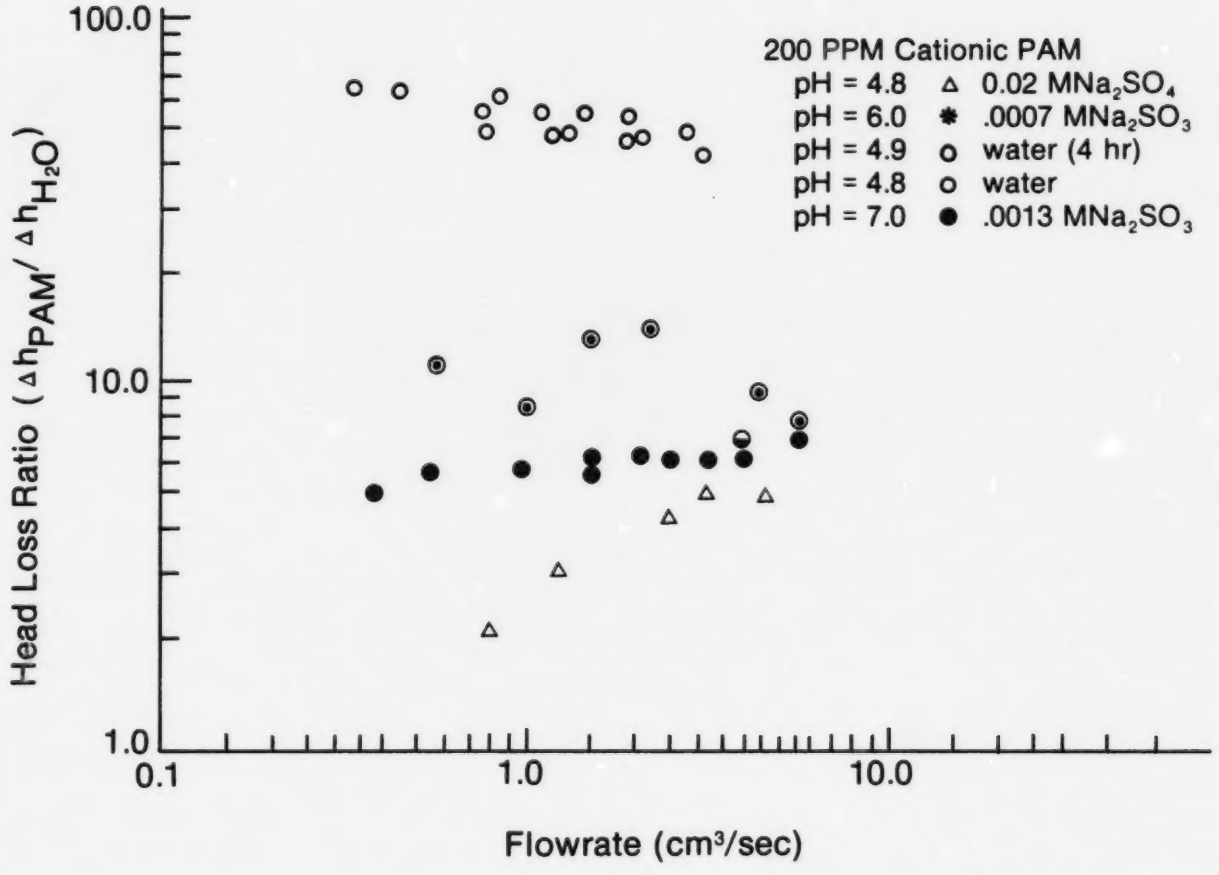


Figure I-21 THE DEPENDENCE OF HEAD LOSS ON THE IONIC STRENGTH OF THE SOLUTION

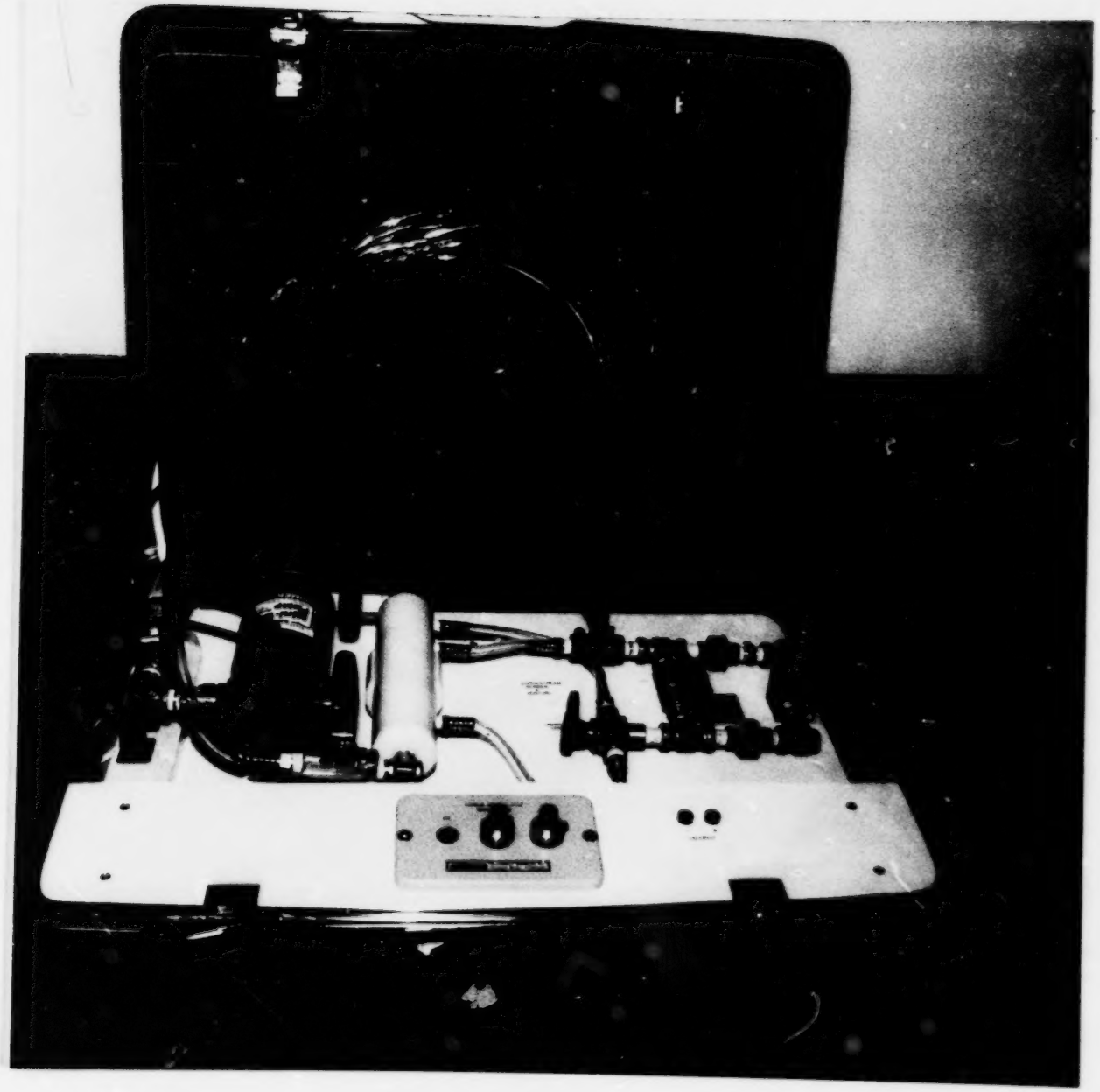


Figure II-1

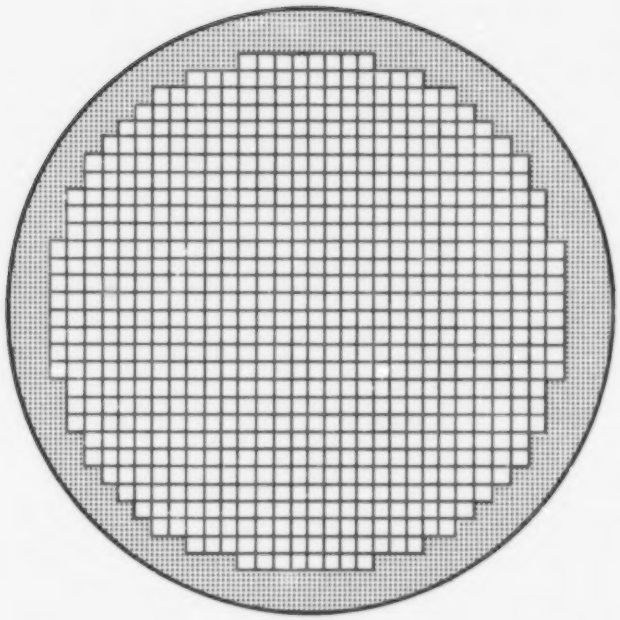


Figure II-2 SCREEN OPENINGS. 724 Exposed Holes.
Void Fraction: 59%

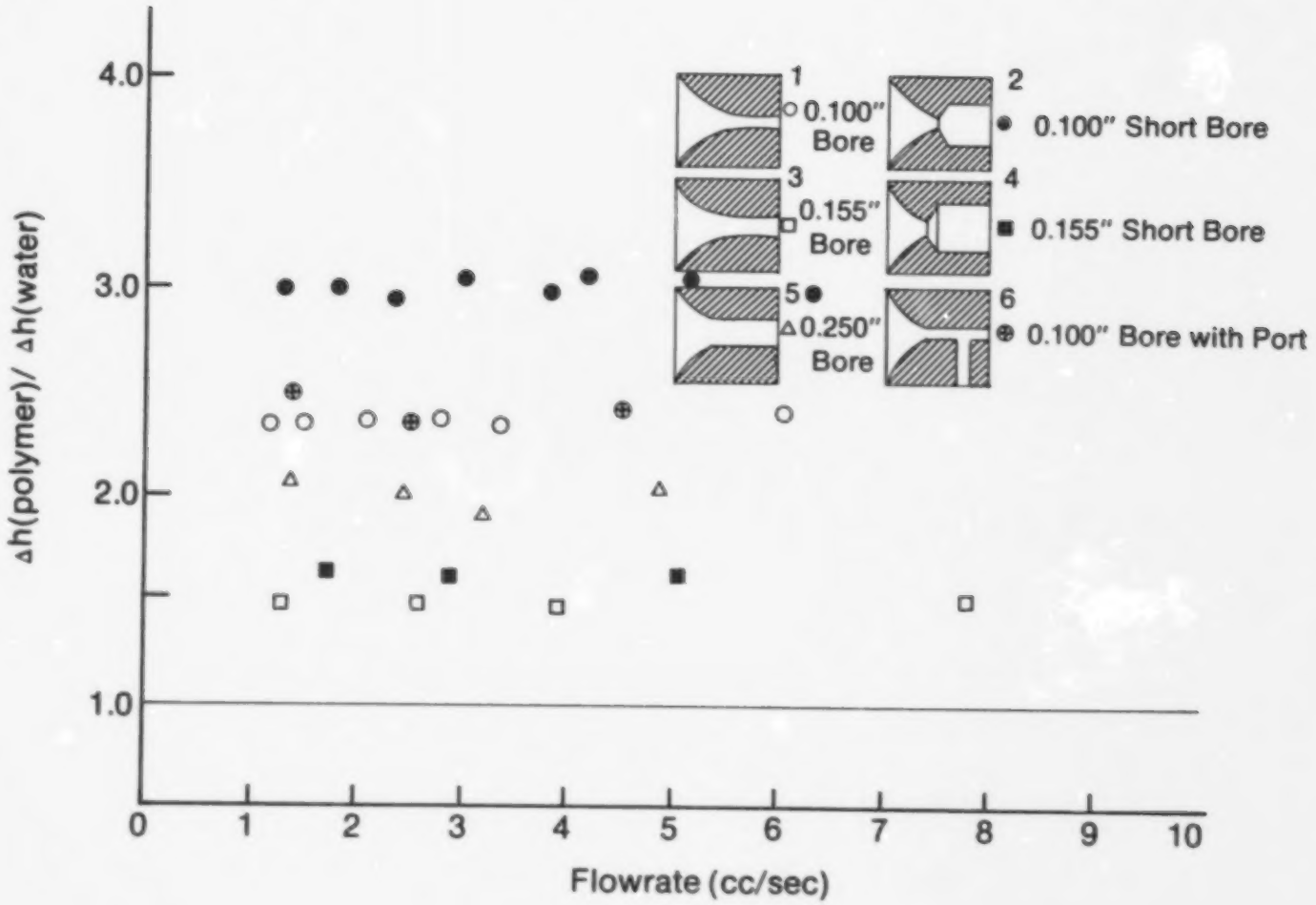


Figure II-3 VENTURI TESTS WITH 500 PPM ANIONIC POLYMER SOLUTION

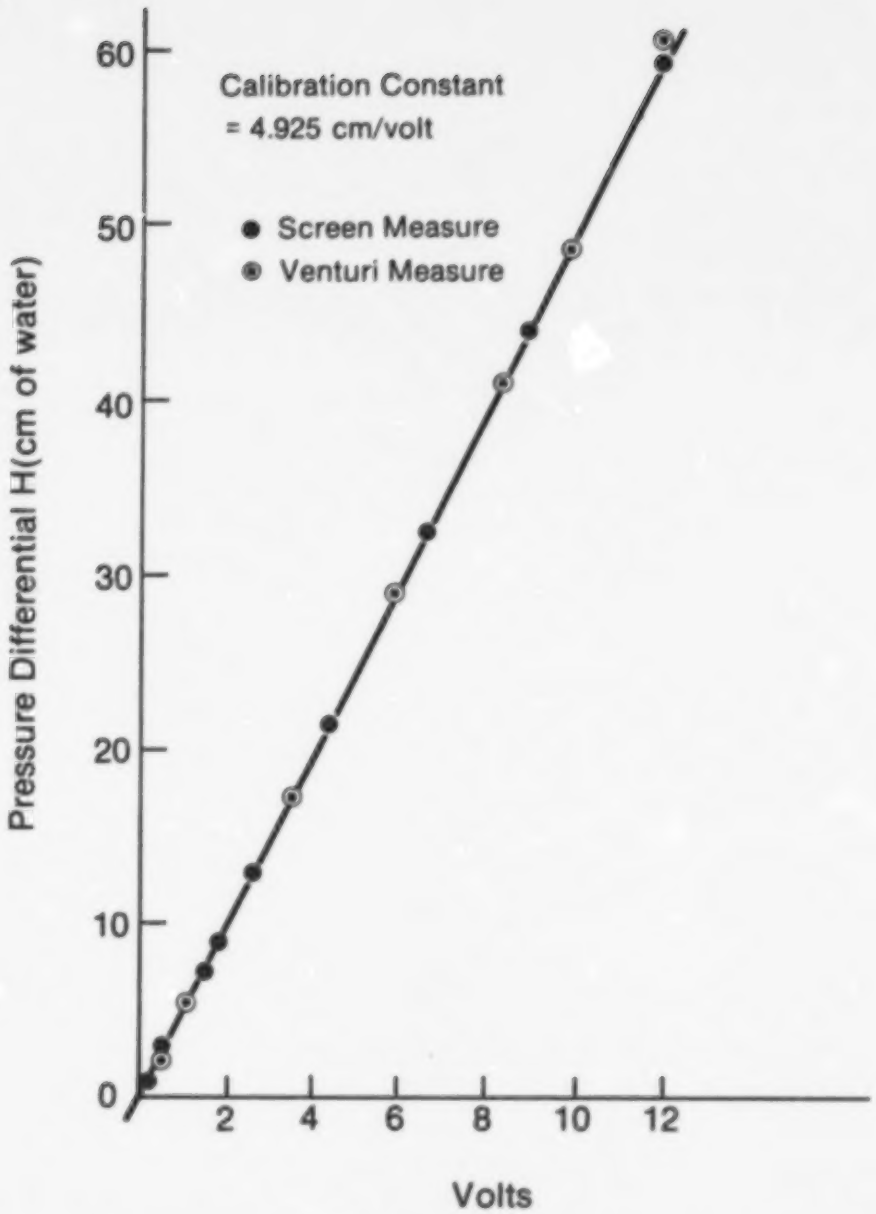
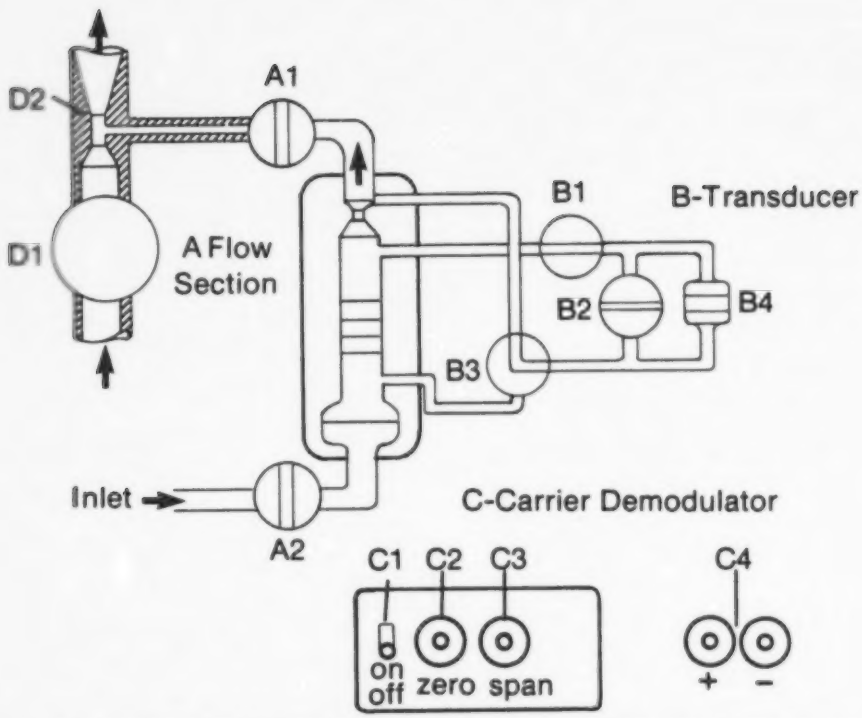


Figure II-4 TRANSDUCER CALIBRATION



A	FLOW SECTION	B	TRANSDUCER	C	CARRIER DEMODULATOR
1	Regulator Valve	1	Shut-off Valve	1	On/Off Switch
2	Shut-off Valve	2	"Zero Check" Value	2	Zero Potentiometer
		3	Selector Valve	3	Gain Potentiometer
D	PUMP/VENTURI	4	Transducer	4	10v D.C. Output
1	Pump				
2	Venturi				

Figure II-5

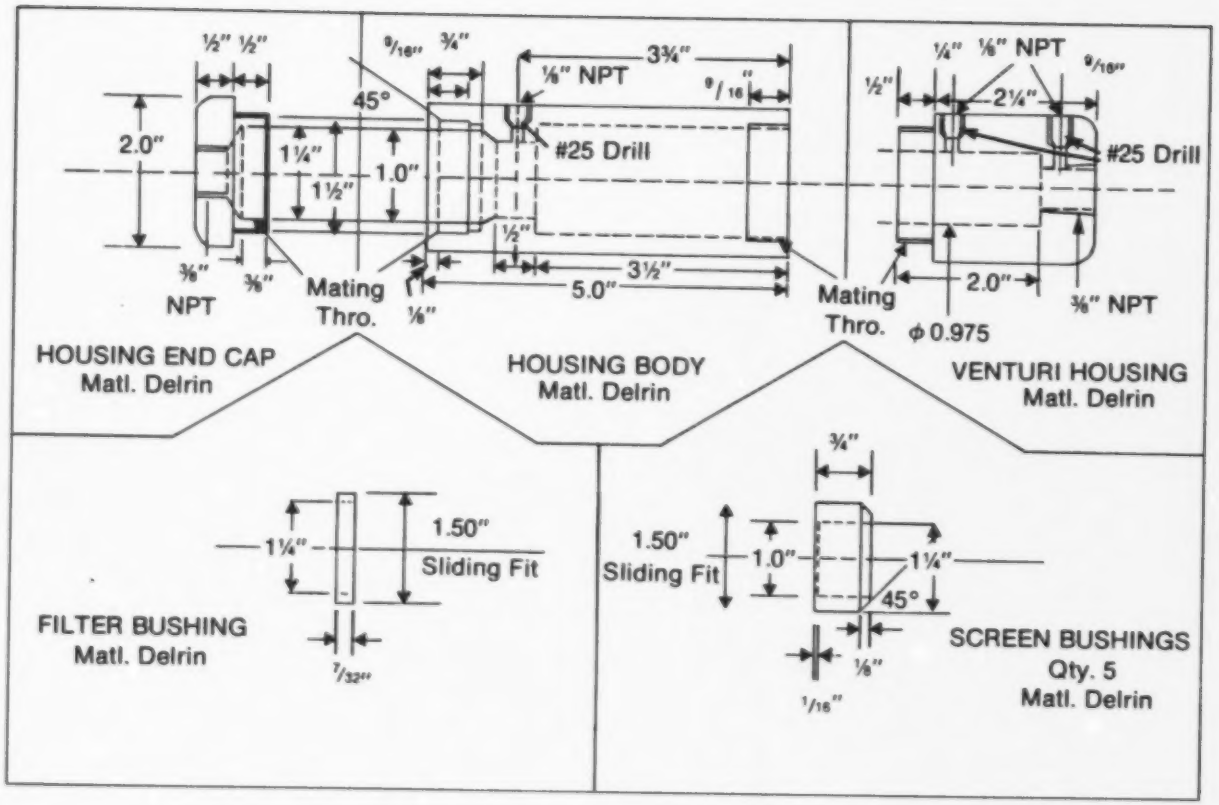


Figure II-6 WRL SCREEN APPARATUS

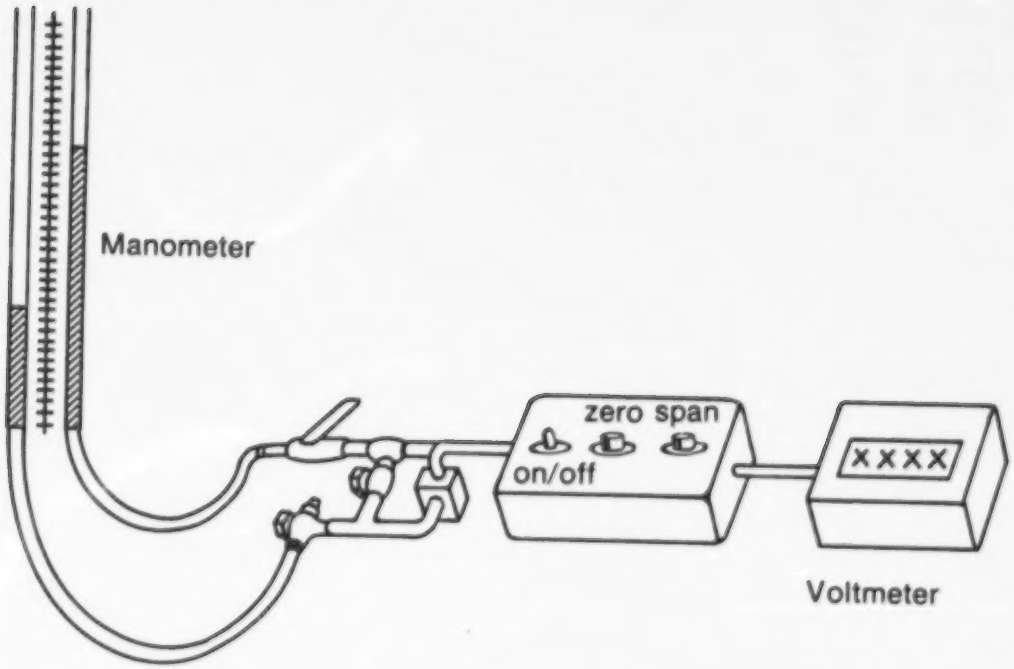


Figure II-7 TRANSDUCER CALIBRATION SCHEMATIC

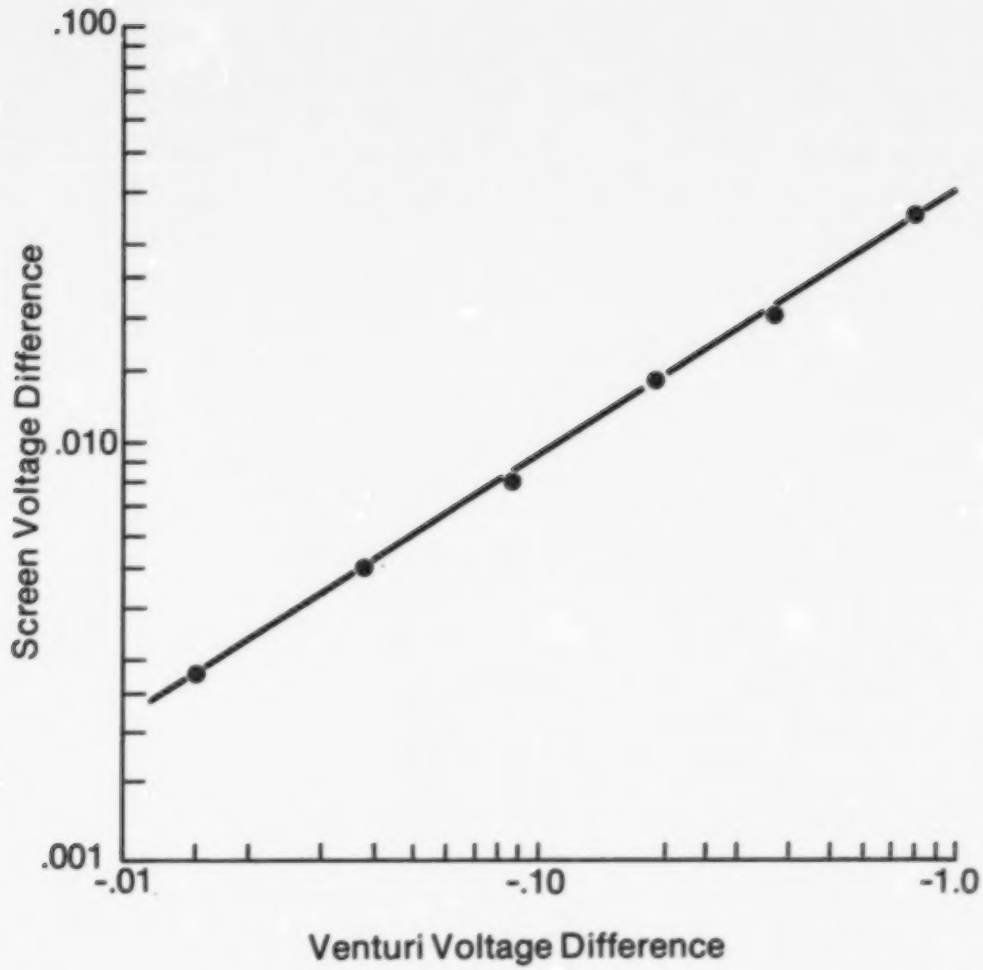


Figure II-8 RELATION BETWEEN SCREEN PRESSURE DROP AND VENTURI PRESSURE DROP. Pressure differential (cm of water) = 5 x voltage.

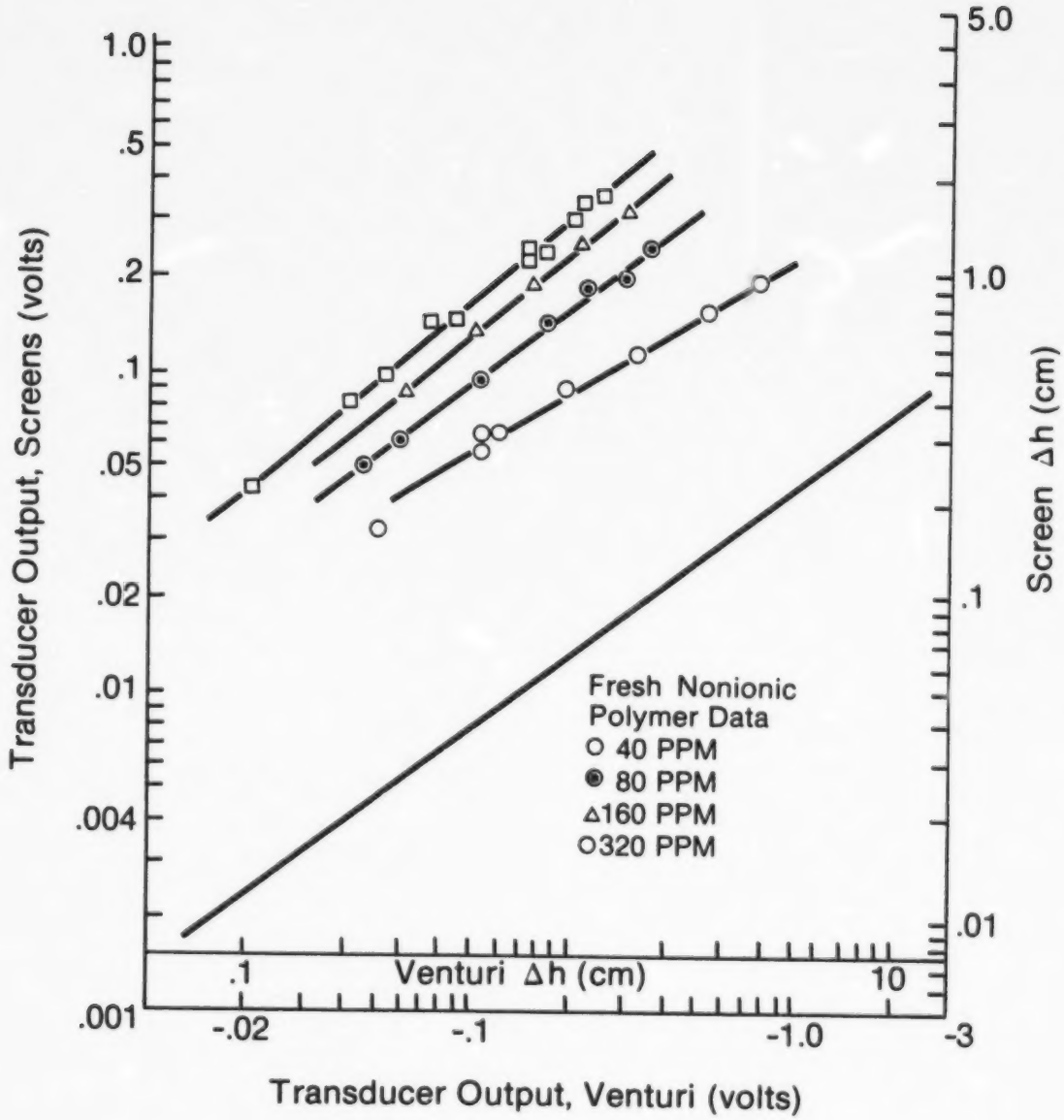

1.0
.5
.2
.1
.05
.02
.01
.004
.001
Transducer Output, Screens (volts)
5.0
1.0
.1
.01
Screen Δh (cm)
Fresh Nonionic
Polymer Data
○ 40 PPM
◉ 80 PPM
△160 PPM
○320 PPM
.1
Venturi Δh (cm)
10
-.02
-.1
-1.0
-3
Transducer Output, Venturi (volts)

Figure III-1

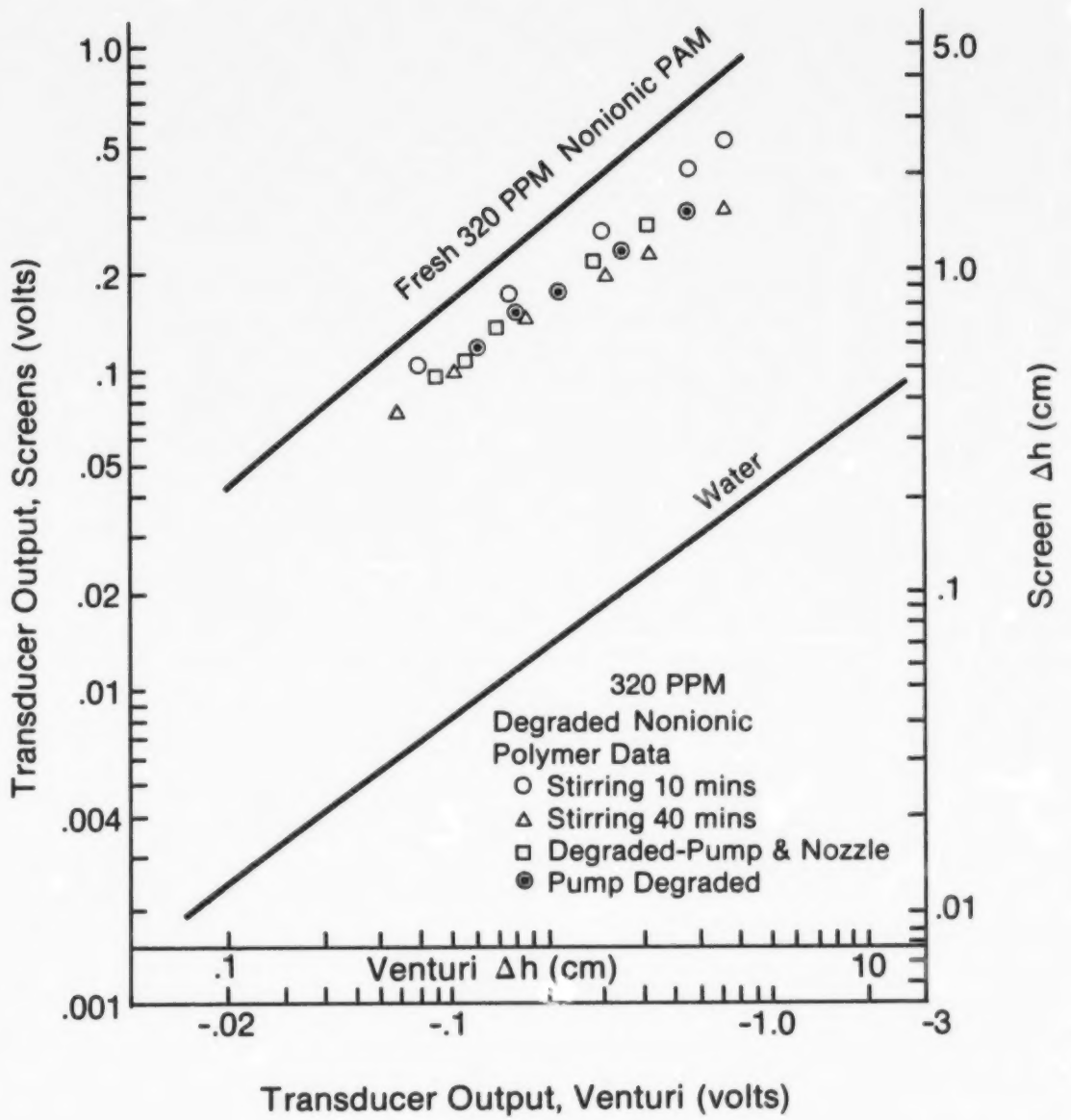

Fresh 320 PPM Nonionic PAM
Water
320 PPM
Degraded Nonionic
Polymer Data
Stirring 10 mins
Stirring 40 mins
Degraded-Pump & Nozzle
Pump Degraded
Transducer Output, Screens (volts)
1.0
.5
.2
.1
.05
.02
.01
.004
.001
Screen Δh (cm)
5.0
1.0
.1
.01
.1
Venturi Δh (cm)
10
-.02
-.1
-1.0
-3
Transducer Output, Venturi (volts)

Figure III-2

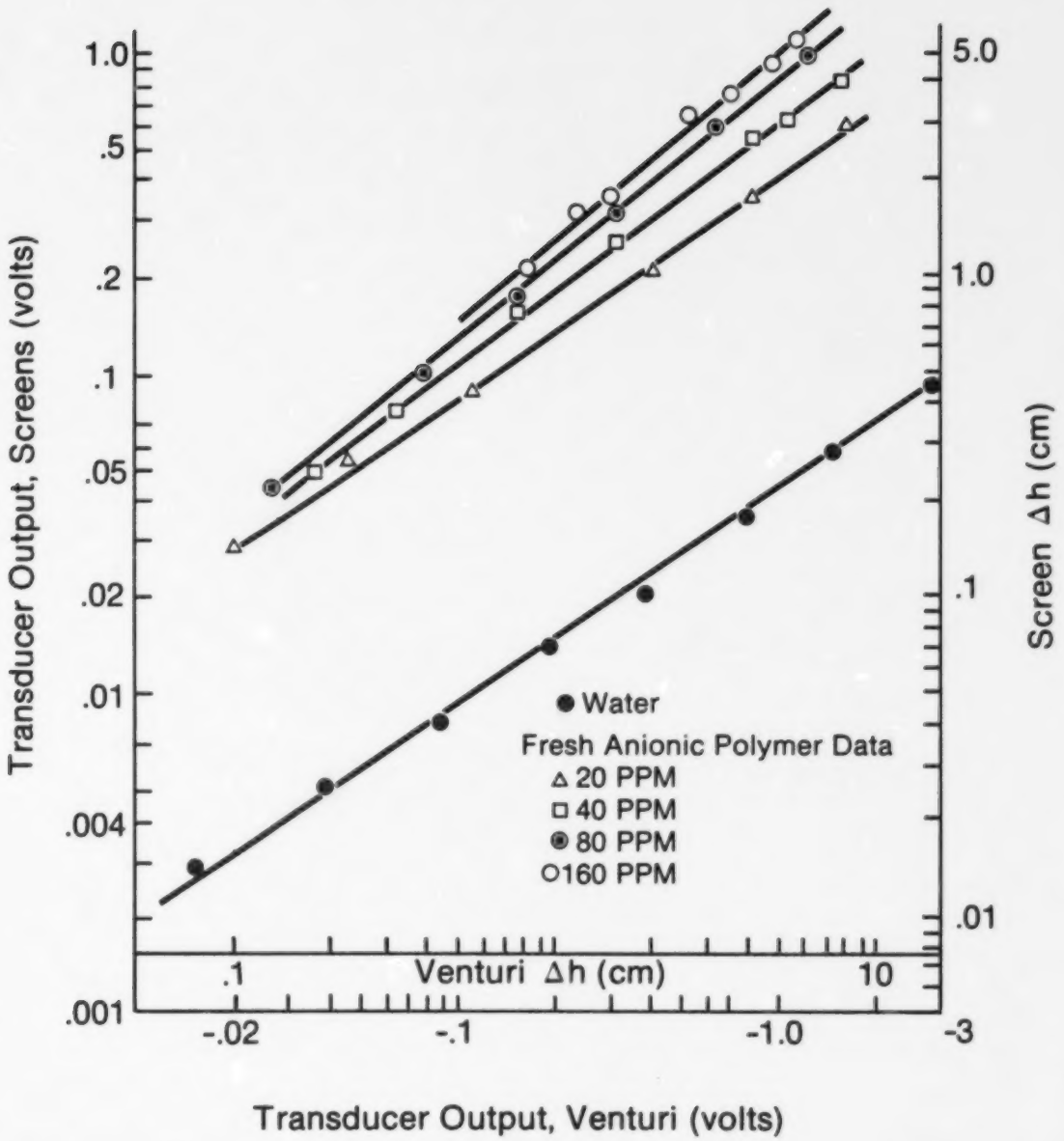

1.0
.5
.2
.1
.05
.02
.01
.004
.001
Transducer Output, Screens (volts)
5.0
1.0
.1
.01
Screen Δh (cm)
Water
Fresh Anionic Polymer Data
△ 20 PPM
□ 40 PPM
◉ 80 PPM
○160 PPM
.1
Venturi Δh (cm)
10
-.02
-.1
-1.0
-3
Transducer Output, Venturi (volts)

Figure III-3

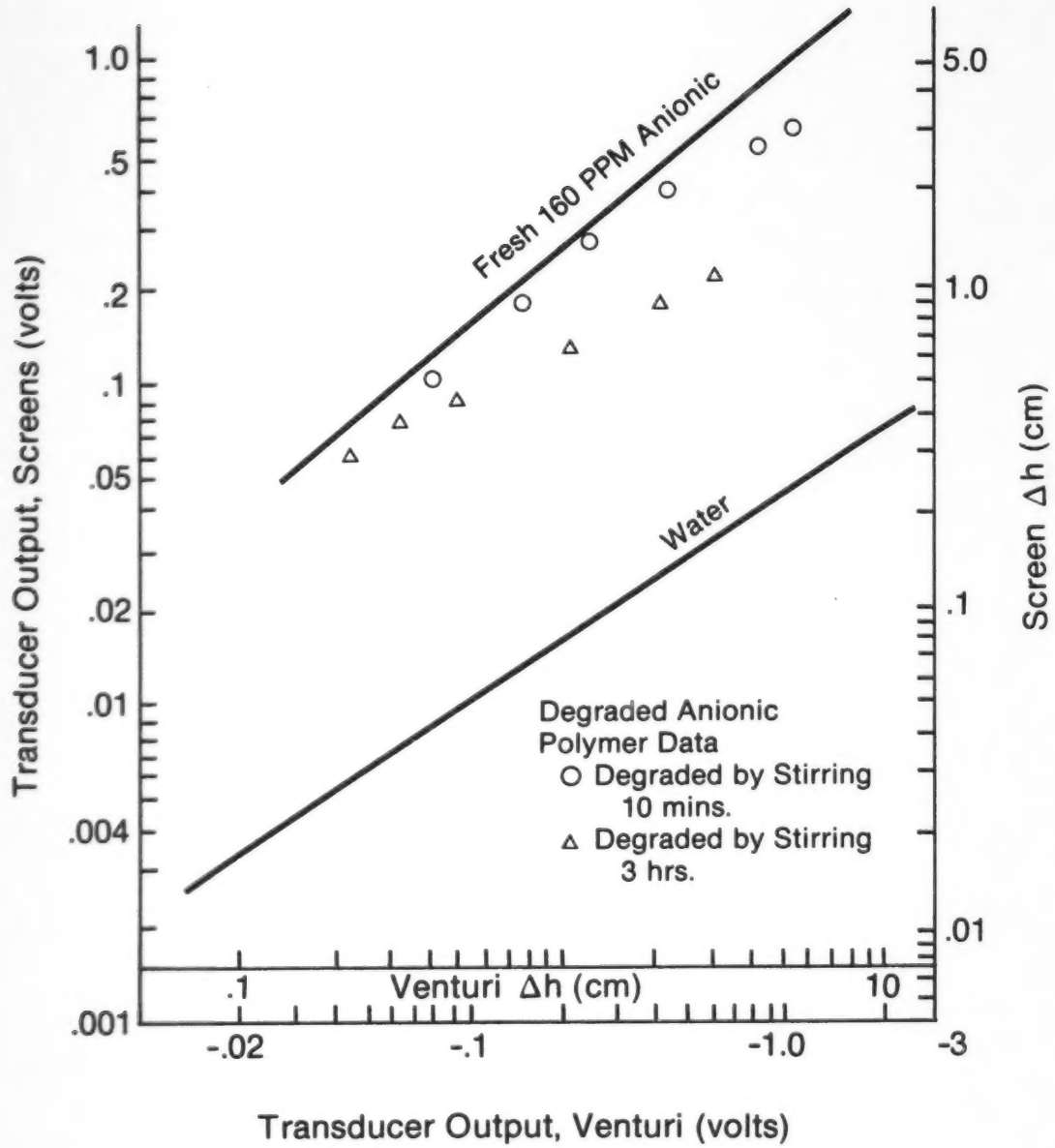

Fresh 160 PPM Anionic
Water
Degraded Anionic
Polymer Data
O Degraded by Stirring
10 mins.
Δ Degraded by Stirring
3 hrs.
Transducer Output, Screens (volts)
1.0
.5
.2
.1
.05
.02
.01
.004
.001
Screen Δh (cm)
5.0
1.0
.1
.01
.1
Venturi Δh (cm)
10
-.02
-.1
-1.0
-3
Transducer Output, Venturi (volts)

Figure III-4

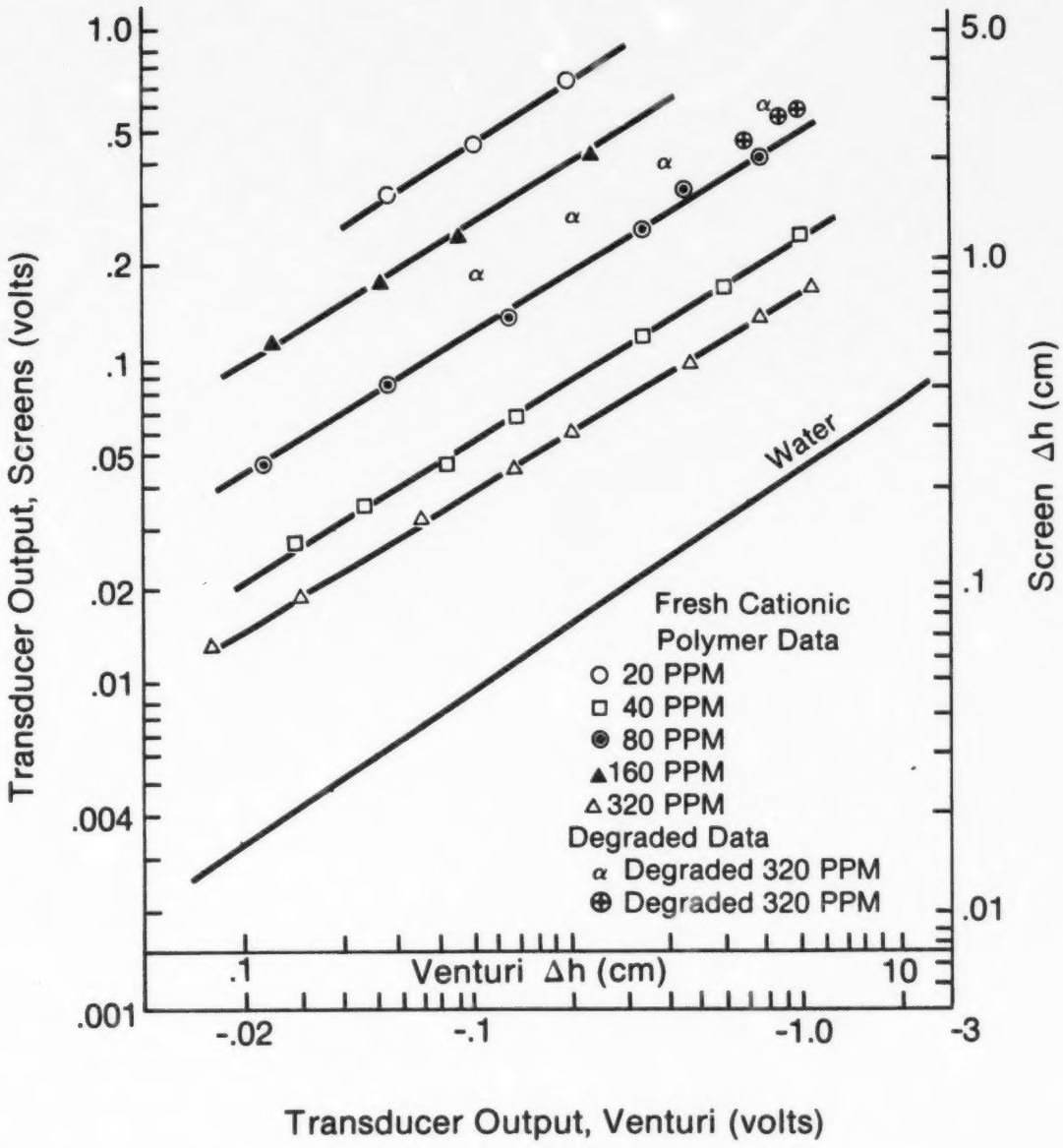

1.0
.5
.2
.1
.05
.02
.01
.004
.001
Transducer Output, Screens (volts)
5.0
1.0
.1
.01
Screen Δh (cm)
Water
Fresh Cationic
Polymer Data
○ 20 PPM
□ 40 PPM
◉ 80 PPM
▲160 PPM
△320 PPM
Degraded Data
α Degraded 320 PPM
⊕ Degraded 320 PPM
.1
Venturi Δh (cm)
10
-.02
-.1
-1.0
-3
Transducer Output, Venturi (volts)

Figure III-5

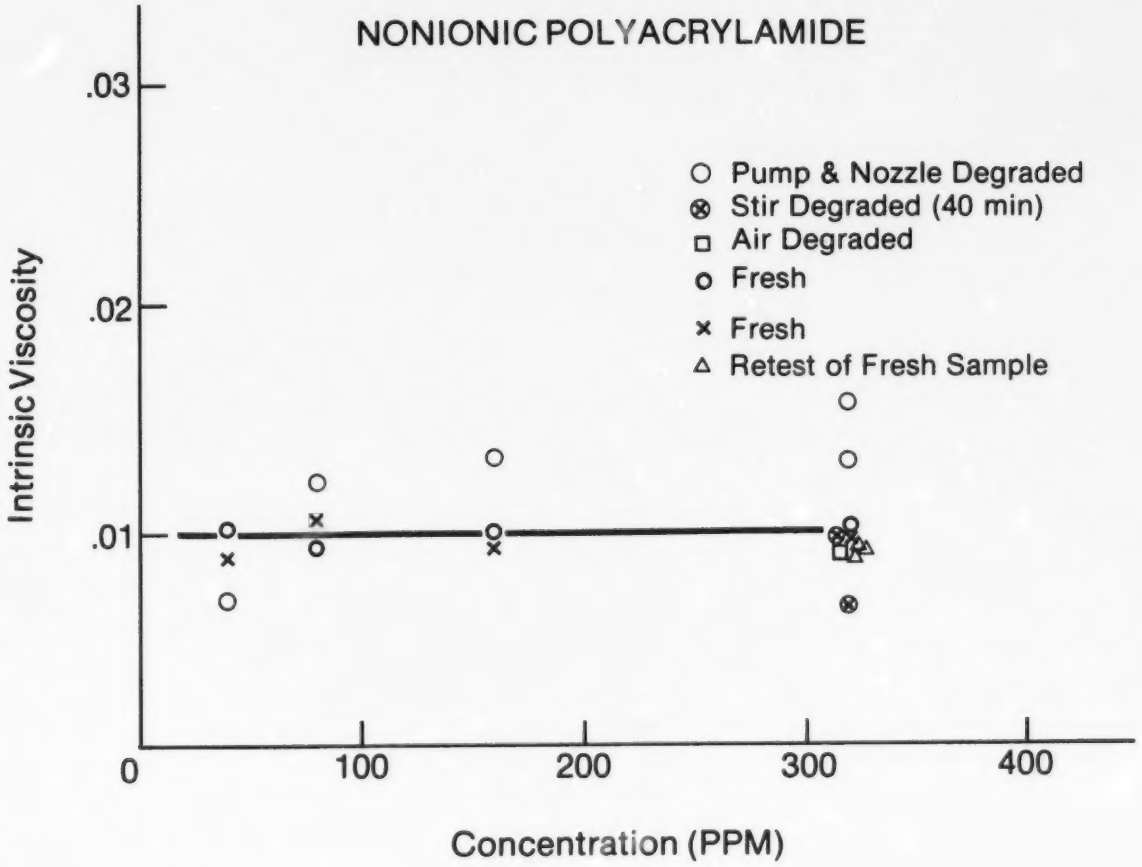

NONIONIC POLYACRYLAMIDE
Intrinsic Viscosity
.03
.02
.01
0
100
200
300
400
Concentration (PPM)
Pump & Nozzle Degraded
Stir Degraded (40 min)
Air Degraded
Fresh
Fresh
Retest of Fresh Sample

Figure III-6

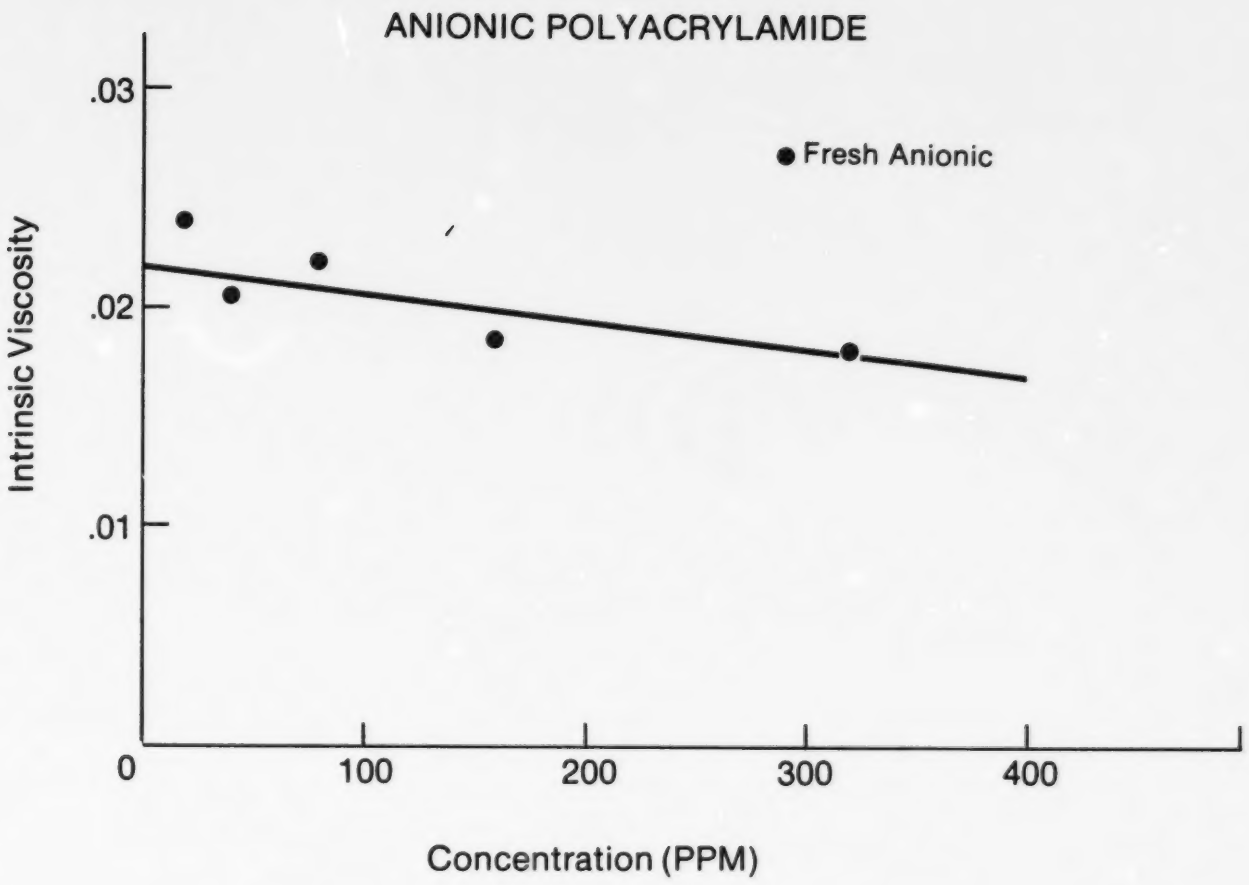

ANIONIC POLYACRYLAMIDE
Fresh Anionic
Intrinsic Viscosity
.03
.02
.01
0
100
200
300
400
Concentration (PPM)

Figure III-7

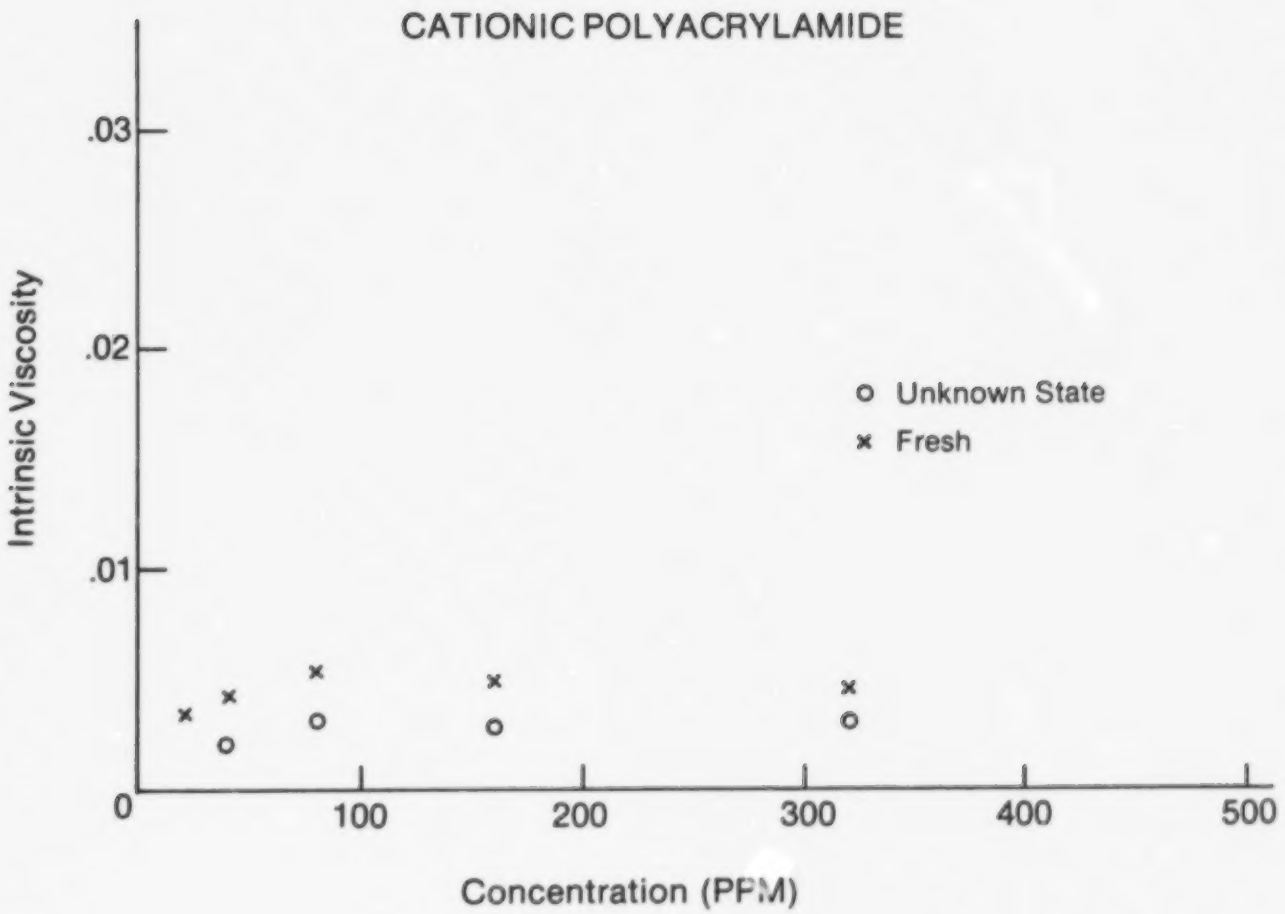

CATIONIC POLYACRYLAMIDE
Intrinsic Viscosity
.03
.02
.01
0
100
200
300
400
500
Unknown State
Fresh
Concentration (PPM)

Figure III-8